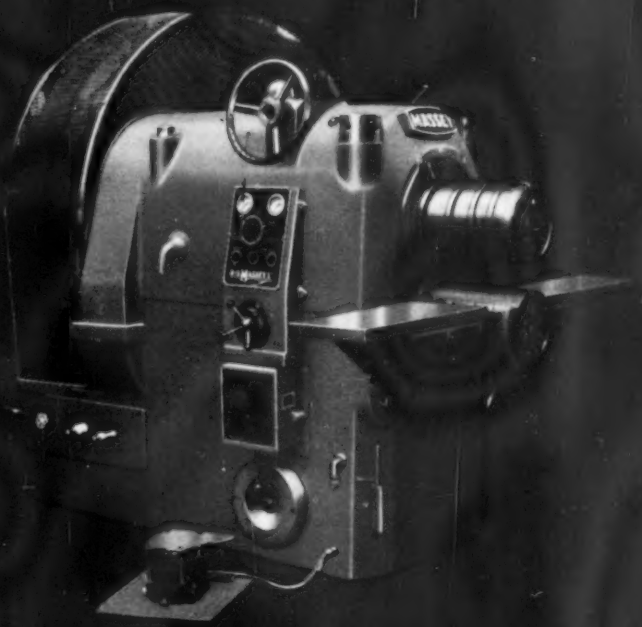
metal treatment

Vol. 26 : No. 169 OCTOBER, 1959 Price 2/6

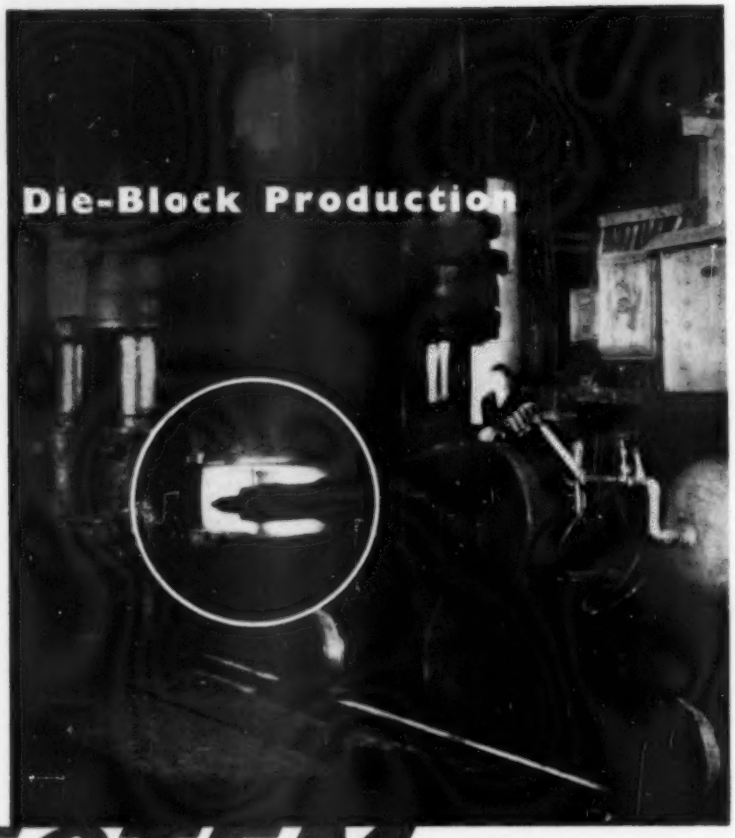
SAVE MATERIALS MAN-HOURS

MASSEY



FEATURES

Specialised Die-Block Production



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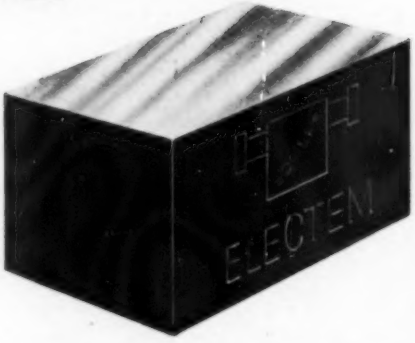
THE MODERN DIE BLOCKS

Electem die blocks are produced in the most up-to-date plant in Europe. Furnaces are automatically controlled; the Heat Treatment bay is designed to ensure absolute accuracy and uniform hardness and every block is individually checked. Our technical experts are always ready to call and discuss any die block problem.



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. . . the best in every case

CONSIDER THESE POINTS:

- Clean working conditions
- Unskilled labour may be employed to carry out the process
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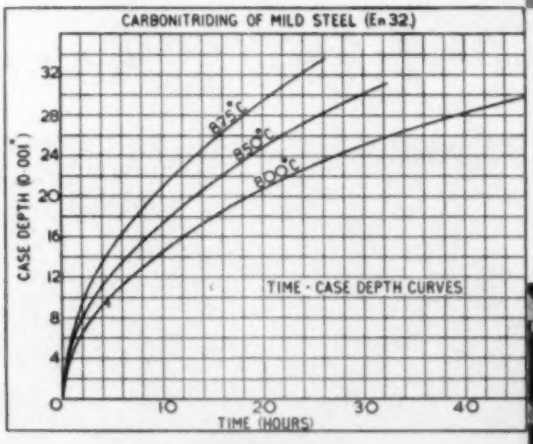
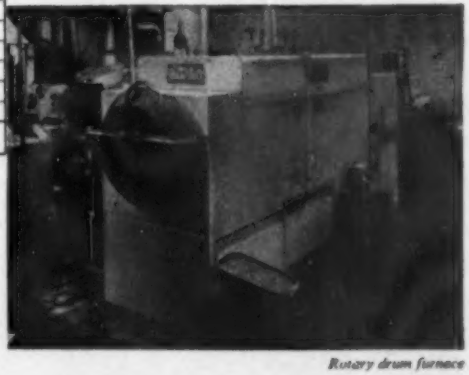
- No storage space required for case hardening materials
- Simple system of atmosphere control

Shaker hearth furnace



- Atmosphere employed is raw Town's Gas and Ammonia
- No costly gas preparation plant required
- Batch or continuous equipment
- Consistent repetitive results



Rotary drum furnace

ELECTRIC WILD BARFIELD FURNACES

FOR *ALL* HEAT-TREATMENT PURPOSES

WILD-BARFIELD ELECTRIC FURNACES LIMITED

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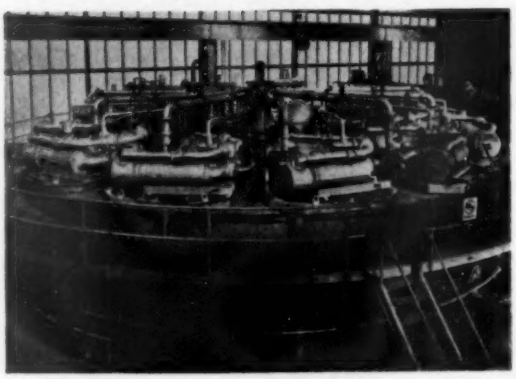
WB 54

Back where they started . . .

An everyday expression which has more than a suggestion of fruitless effort, of time and energy wasted. Yet in production layout the converse is often true : time and manpower can frequently be saved by intelligent use of circular flow. The rotary furnace is an ideal embodiment of the principle, since the work is heated throughout its travel, and charging and discharging points are side by side.

And of course Incandescent rotaries have a further advantage, since they can be fitted with the Equiverse system of scale-free heating. The illustration on the right shows such a furnace with Equiverse firing, used for heating steel billets for extrusion at a rate of 10 tons an hour. Steering box components are being heat-treated in the two open-fired rotaries shown above.



INCANDESCENT

THE INCANDESCENT HEAT CO. LTD. · SMETHWICK · ENGLAND
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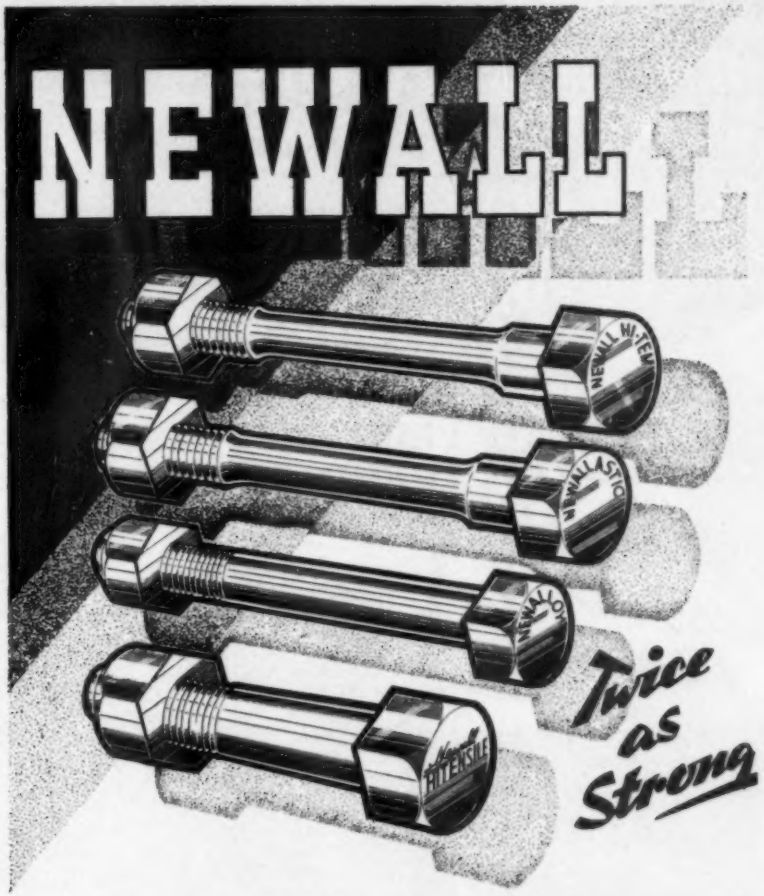

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are recognised by engineers as having unique qualities. We shall be happy to supply any engineer designer who is interested with details of the various bolts and studs, which cover the full range of modern requirements.

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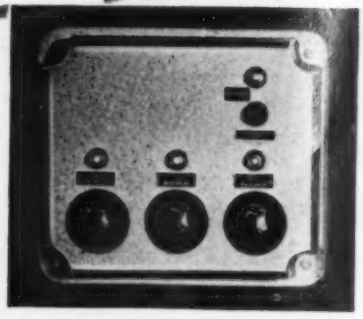
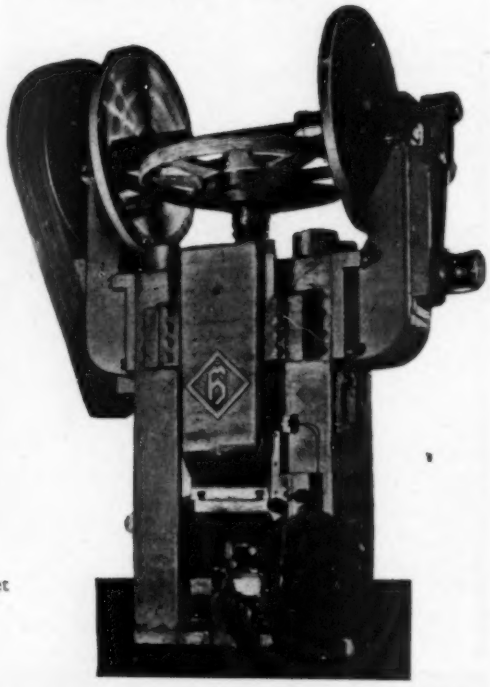
NEW Electronic Control





A unique feature of these presses enables cycle, blow and programme to be preset accurately. Push button operated models from 150 to 3,000 tons are available for hot or cold forging or coining.

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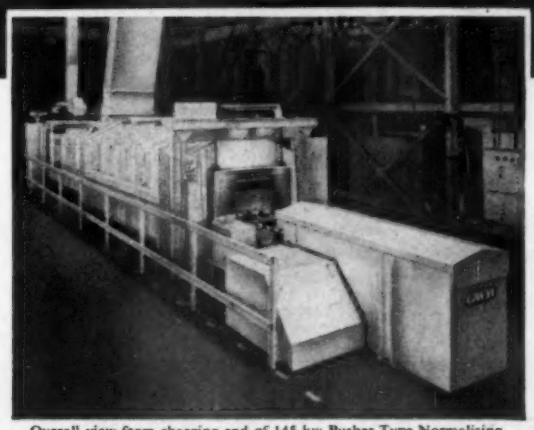
ALBION MOTORS AND G.W.B.

One of the oldest manufacturers of commercial motor vehicles in this country,
Albion Motors keep up to date in their manufacturing methods
by installing the latest and most efficient equipment available.
An example is the electrically heated Pusher Furnace supplied
by G.W.B. Furnaces Limited.



Overall view from charging end of 145 kw Pusher Type Normalising Furnace at Albion Motors Limited.

APPLICATION Various forgings such as main shafts, countershafts, pinion shafts and gear blanks are normalised by heating up to 900° C. and slow cooled down to 400/500° C.

AUTOMATIC OPERATION The only labour required is for placing the components into the charge trays at the entrance end of the furnace. By pressing a button, the following cycle automatically takes place. (1) The entrance door rises. (2) The pusher ram propels the loaded tray into the furnace. (3) The ram returns. (4) Entrance door lowers. (5) Exit door rises. (6) Hydraulically operated go-getter pulls last tray from exit end of furnace on to a cross conveyor. The cross conveyor moves the normalised parts to the top of an inclined roller track where the tray is unloaded by a tipper, and then returns empty to the entrance end of the furnace.

OUTPUT 600 lbs. of normalised forgings per hour.

GWB

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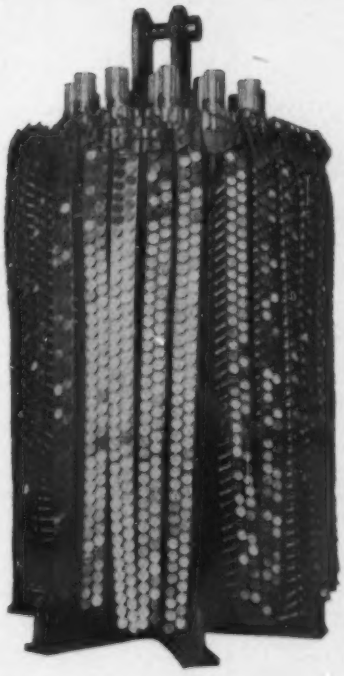
Economy pack

Compactness of furnace layout is matched by the amazing density of loading in these INCANDESCENT gas carburising furnaces. Such performance is made possible by two special INCANDESCENT features

Circulating fan which ensures consistent uniformity of case depth.

Jetube heating with its special recirculation system which transmits heat to the load with maximum speed and efficiency.

Photographs by courtesy of The Ford Motor Co. Ltd.



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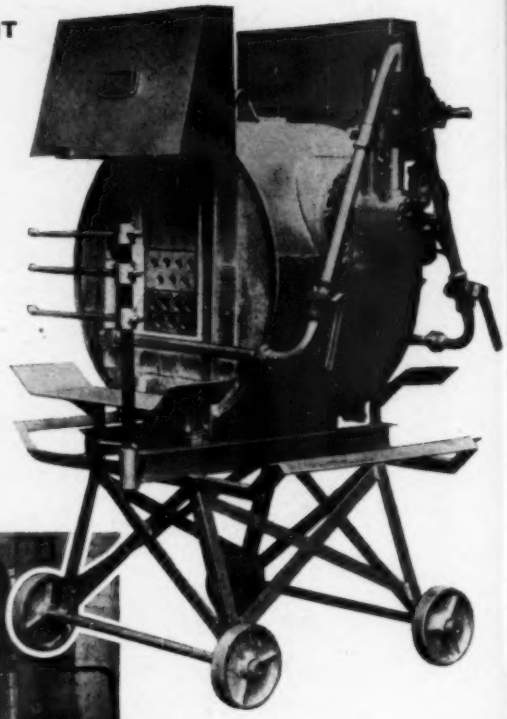

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CLEAN ATMOSPHERE.
IMPROVED OPERATING CONDITIONS.
LOWER RUNNING COSTS.
REDUCED MAINTENANCE.
LESS WASTAGE,
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Oil-fired Slot Type Forge Furnaces

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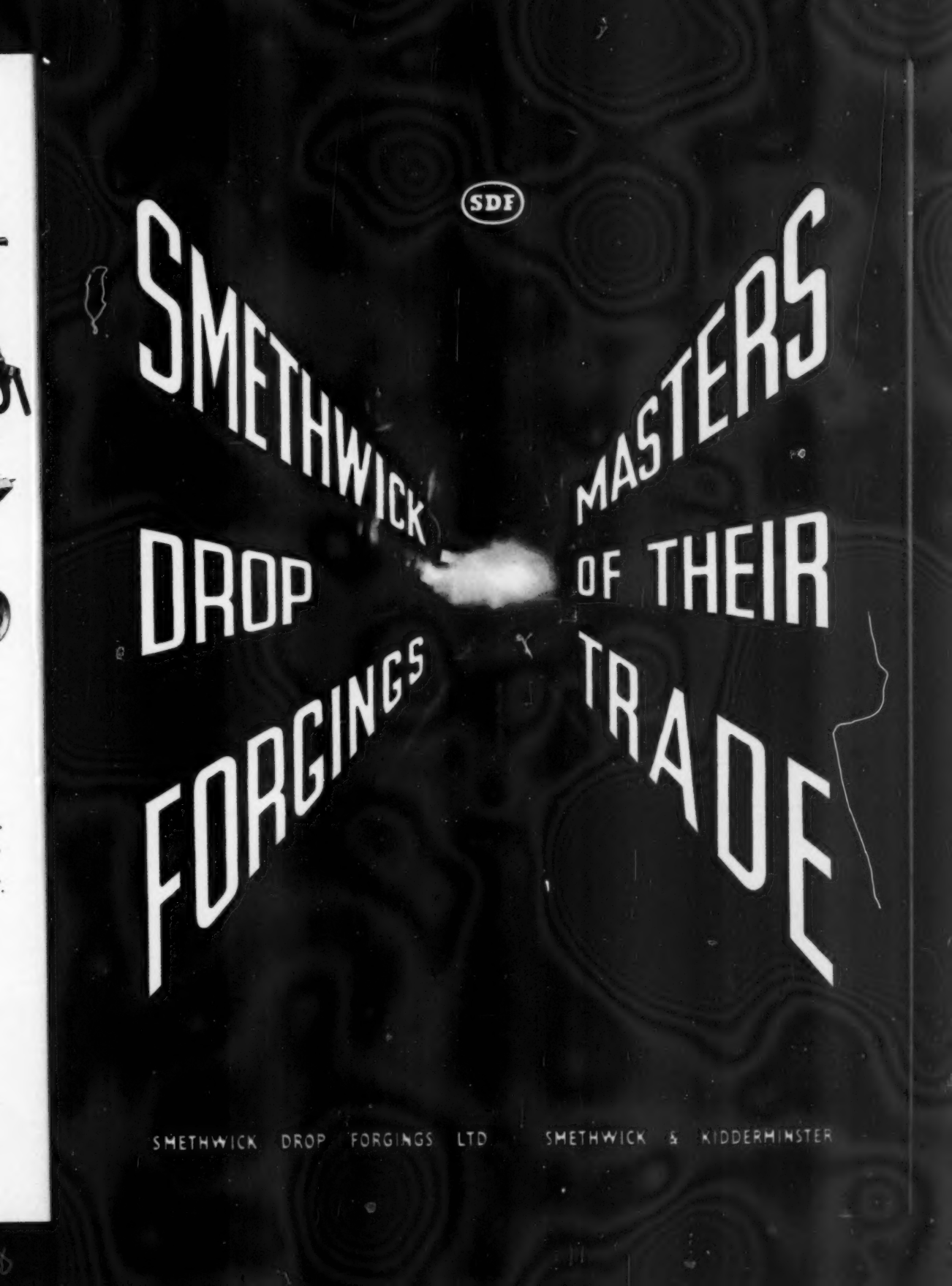
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MASTERS OF THEIR TRADE
SMETHWICK DROP FORGINGS LTD
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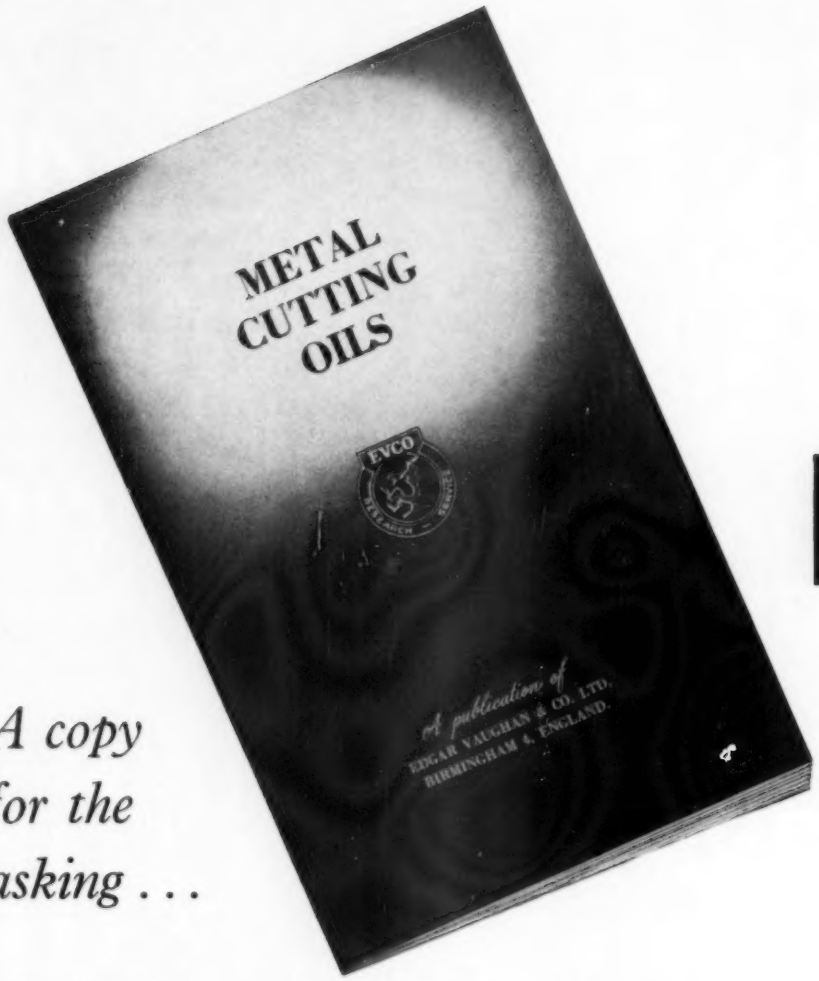

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In days when time is money and competition gets keener, the importance of cutting oils and lubricants is often overlooked.

To help engineers and others concerned with the selection of the *right* cutting oil for a particular operation, we have produced the above booklet. If you have not received a copy, please—in your own interest—write for one to-day, without obligation.

The booklet is not a general treatise on cutting oils. It is, nevertheless, a helpful guide in the selection—with the advice of Edgar Vaughan & Co. Ltd.—of the most suitable and economical oil or lubricant for a specific job of work.

In a general way, the booklet covers Neat Cutting Oils, Broaching Oils, Soluble Oils of all types, Grinding and Drawing Compounds.

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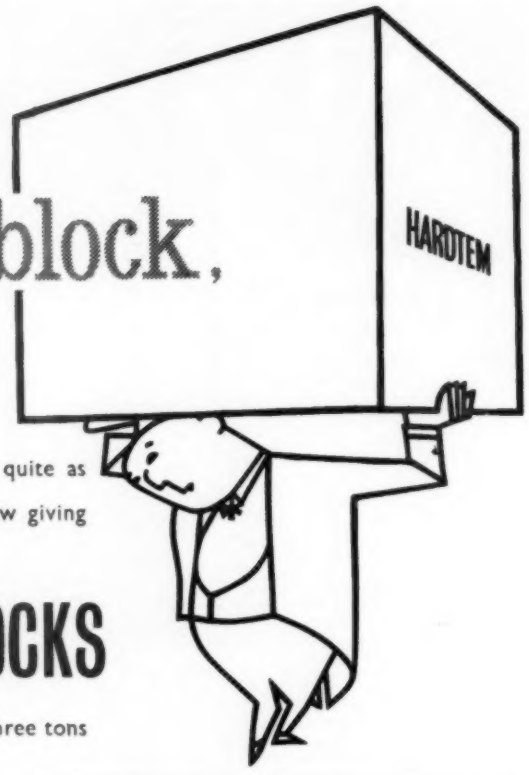
Your die block, Sir!



Service to stamping shops isn't quite as easy as that, but Jessops are now giving rapid delivery of

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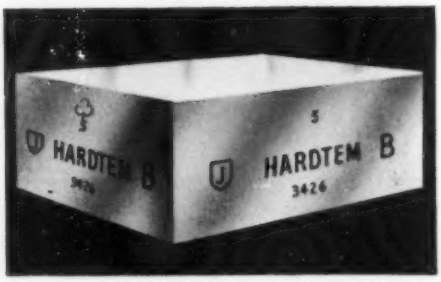
now available in weights up to three tons



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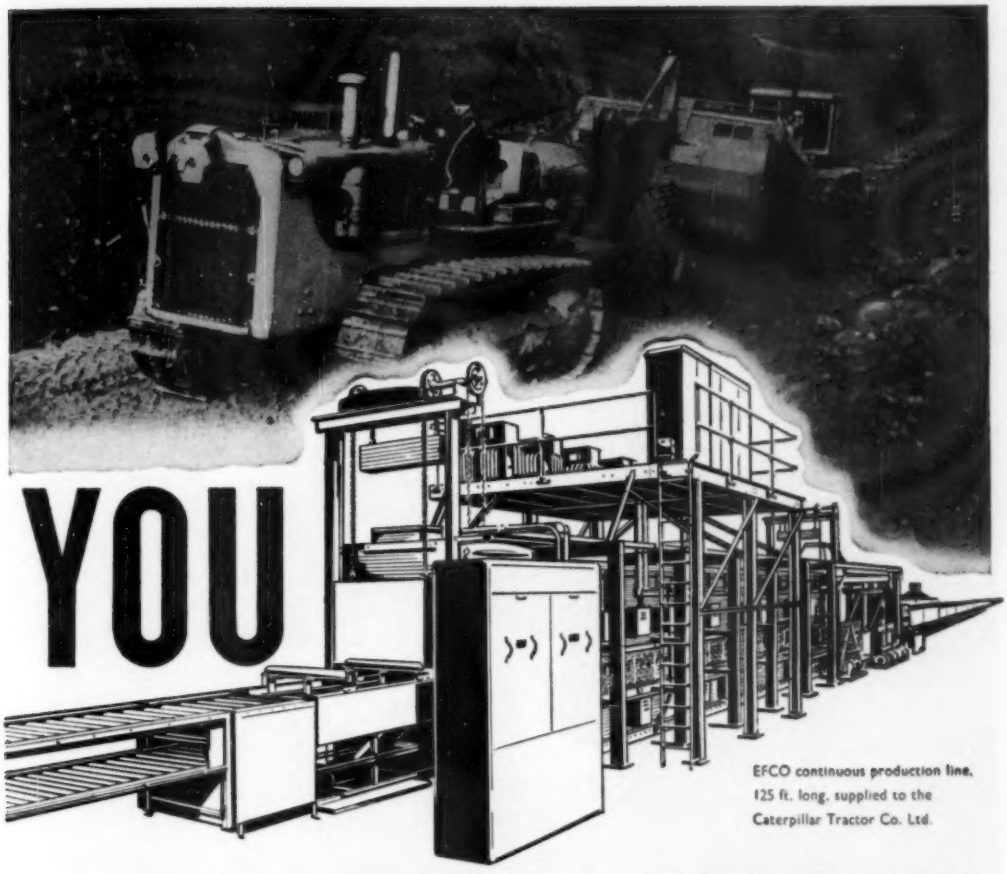

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EFCO

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Chromium	·01	·015
Copper	·03	·04
Arsenic	·015	·02
Tin	·015	·02
Vanadium	·02	·04
Molybdenum	*below* ·01	
Lead	*below* ·01	
Cobalt	·005	·008
Antimony	*below* ·01	
Tungsten	*below* ·01	
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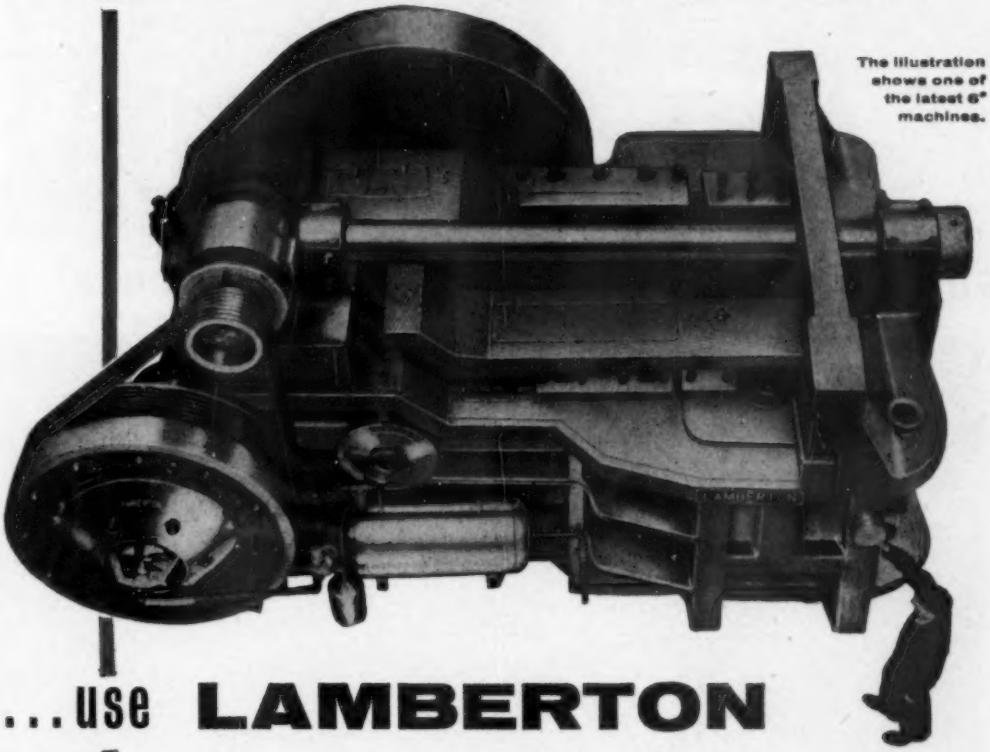

The illustration shows one of the latest 6" machines.

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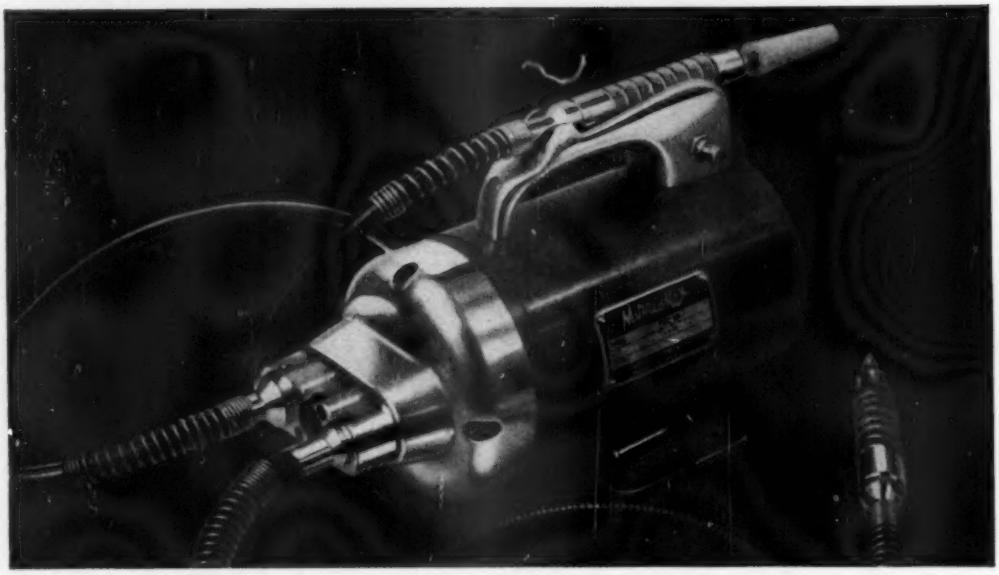

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USE SECAR 250
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Higher Temperatures up to 1800°C.
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Recirculation Furnaces

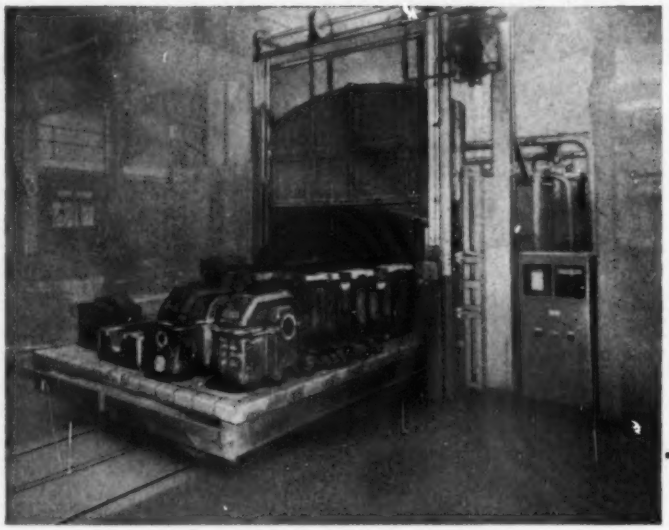

Illustration shows one of our furnaces at Messrs. David Brown Industries Ltd., used to heat-treat fabrications for their famous Radicon gear boxes.

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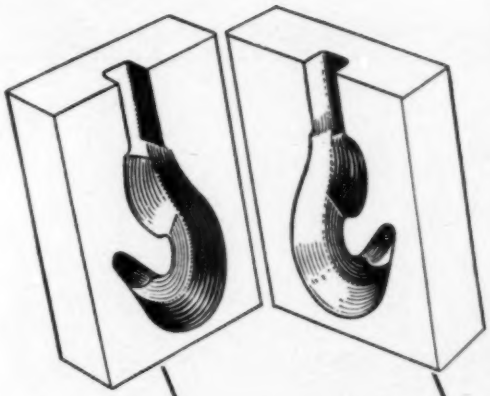
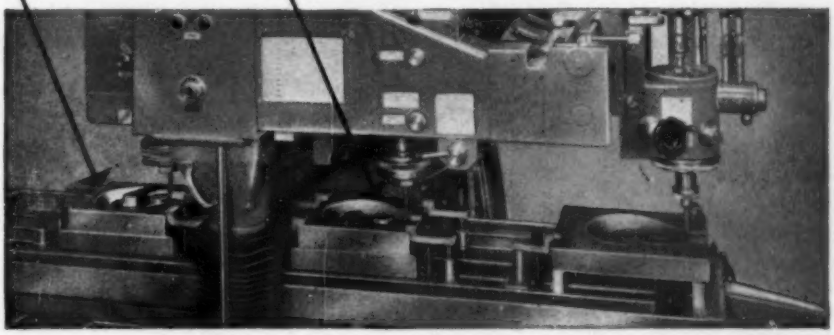


Both halves at once



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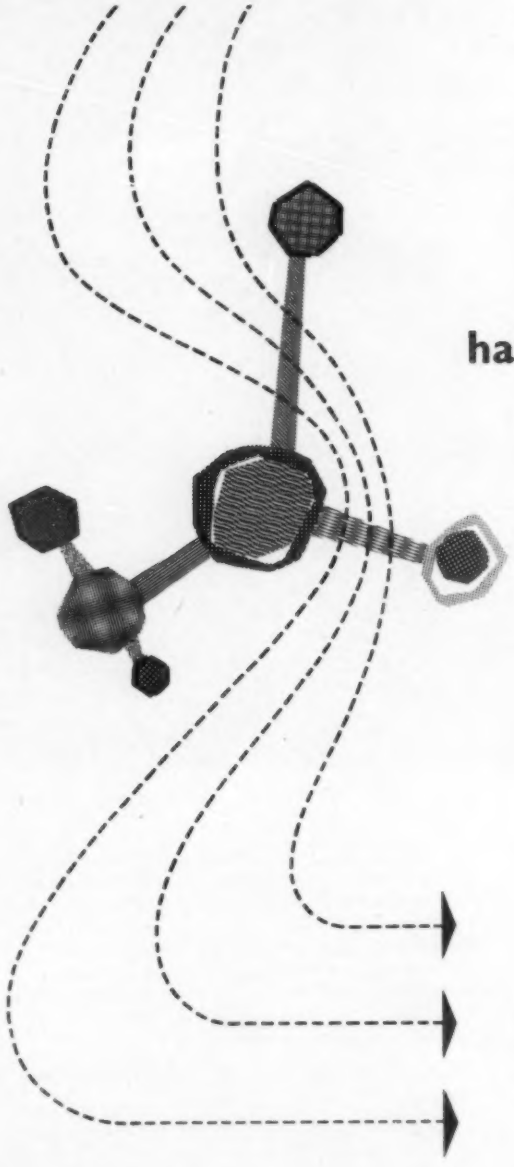

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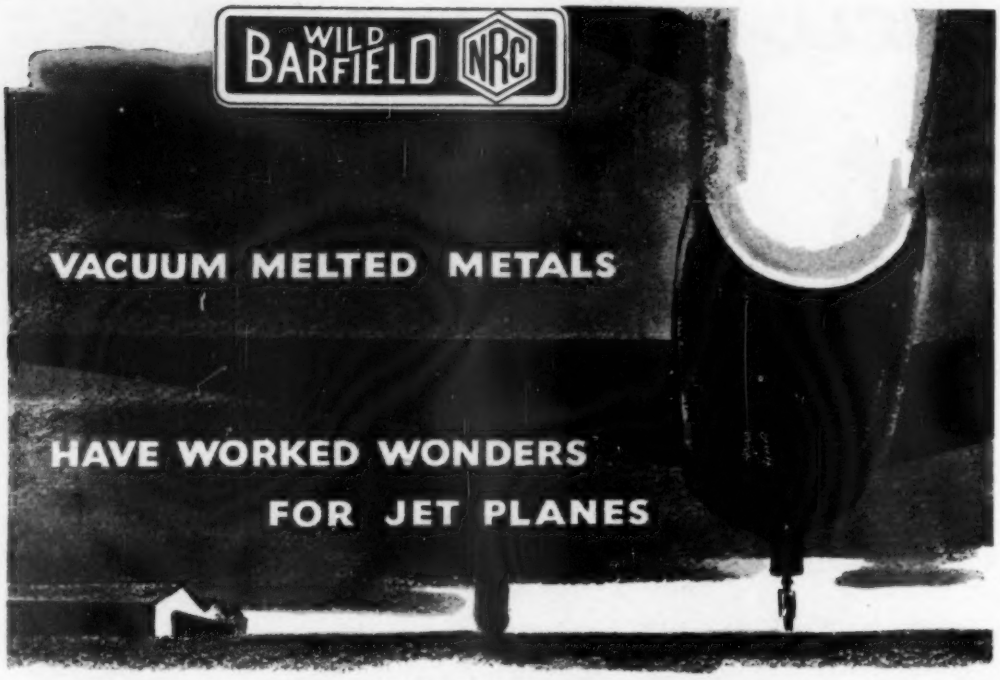

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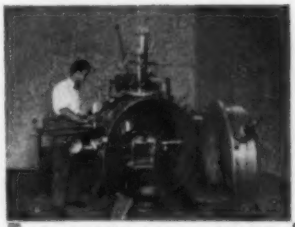

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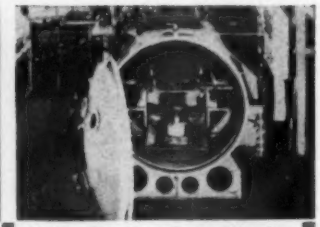

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October 1959

Vol 26, No 169

Metal treatment

and Drop Forging

Editor D. J. O. BRANDT B.SC., A.R.S.M., F.I.M.

Assistant Editor F. D. GRIMMER

Advertisement Manager J. M. DICKIE

Production Manager R. J. LOVELL

Publisher H. J. DWYER

Scottish Area Manager T. H. SMITH

Official organ of the NATIONAL ASSOCIATION OF DROP FORGERS AND STAMPERS

President J. H. SWAIN

Director A. L. STUART TODD, C.B.E., J.P.

Grove Hill House, 245 Grove Lane Handsworth, Birmingham 20

Telephone NORthern 3311-3

Published on the 15th of each month by

AN INDUSTRIAL NEWSPAPERS PUBLICATION

INDUSTRIAL NEWSPAPERS LIMITED

John Adam House
17-19 John Adam Street
Adelphi, London W C 2

Telephone TRAfalgar 6171 (10 lines)

Telegrams Zacatecas, Rand, London

Subscription Terms Home and Overseas 30*s* per annum prepayable

Single copies 2*s* 6*d* (3*s* 0*d* post free)

CONTENTS

This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

345 **Spark machining**

347 **A survey of chipless forming** DIPL.-ING. W. BIEDERSTEDT and DR.-ING. H. MEYER

New methods, machines and finished work at the exhibition on chipless forming organized by the Hanover Technical College this year

361 **Hot working of alloy steels** Part 3 Influence of structure and composition A. GUEUSSIER and R. CASTRO

367 **Application of electron microscopy** Structure of pearlite formed during the continuous breakdown of austenite IVAN HRIVNAK

374 **Beryllium copper** Part 2 Heat treatment

G. FITZGERALD-LEE, F.R.ECON.S., M.I.E.I., A.R.Ae.S.

381 **Fulmer Research Institute**

Brief descriptions of metallurgical work in progress indicating the facilities available for research.

385 **News** 386 **People** 387 **New plant**

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Spark machining

THE ever increasing necessity of economizing production costs and labour requires of the manufacturer an up-to-date knowledge of alternative processes and techniques. That many are fully alive to this responsibility was well illustrated last month when the National Association of Drop Forgers and Stampers held a one-day symposium on spark machining in Birmingham. Representatives of such divergent industries as brass, glass, plastics, toolmaking and drop forging were to be found among the 280 delegates, who included delegates from the Continent, and much lively discussion was provoked by the papers.

Mr. J. H. Swain, president of the NADFS, opening the symposium, said the technique of machining metals by electrical spark erosion had made rapid progress in recent years and he believed it was right to say that further developments were still taking place. It had been demonstrated already that when conditions were favourable considerable savings in machining and in finishing times could be achieved with less costly labour. Furthermore, a high standard of surface, accuracy and uniformity on repeated impressions could be maintained with less skill on the part of the operator.

At the close of the symposium, Mr. W. E. Golcher, chairman of the Technical Committee of the NADFS, said that he believed the conference had been very adequately justified. It had gathered together a great deal of information on spark machining, and had certainly shown its possibilities in many directions. It had also thrown up many problems yet to be solved.

What were the thoughts which the delegates would take away with them—thoughts for the users and potential users, thoughts for the makers of the equipment? One of the principal thoughts that the drop forgers present, and perhaps some of the other trades who were interested, would take away was the possibilities offered by this new cutting tool in the reconsideration of die materials. Up to the present they had been limited largely to materials which could be cut either in the hardened or in the annealed condition. There had always been potentially valuable die materials which the industry had been unable to shape to the intricacies required. The development of spark machining might well enable the industry to rethink those problems quite drastically. Other problems in connection with the manufacture and design of electrodes and flushing away debris had been brought up. It had become clear that if spark machining was to be successful it had to be thoroughly engineered into the die shops of the various industries.

Dealing with the problems for the makers, Mr. Golcher said that they had quite properly conceded that they must give further thought to the location of electrodes in their machines and to locating equipment. He suggested that they had problems also in designing their newer machines, particularly for larger work when they would have to remember that many of the articles to be eroded were of great weight, awkwardness and shape.

How would these problems be dealt with? In Britain there was a great tradition of individuality in companies helping themselves. There was a feeling widely held by many user industries that these problems were the problems of the machine manufacturer. Mr. Golcher suggested that this was only a partial truth. The problems of application and engineering were always with the user, and there was a considerable overlap between user's problems and the problems which the machine manufacturer could legitimately be asked to solve.

In Britain there was a rapidly expanding system of advanced technical education. There was, for example, the Birmingham College of Advanced Technology which had many

facilities. In the next year or two it would have even greater facilities, not only to train all kinds of engineers to a very high standard to the new Diploma of Technology, but also well equipped and anxious to accept research problems or application and development problems for post-graduate students.

It might not be easy for individual companies to place problems with the colleges or, for that matter, with the research councils and research associations whose representatives were also welcomed at the symposium. It might be a problem which could be sponsored jointly by trade associations. The NADFS was giving very active consideration to what could be done in that respect. It was very conscious of many of the problems which needed a joint approach and were not easily tackled, even in the larger firms in the industry, and were certainly not capable of being tackled by the smaller companies. That might well be so also in the other trades represented at the symposium.

It was extremely important for the continued industrial wellbeing of this country—that meant the wellbeing of the whole population and those in industry particularly—that these problems should be tackled. Certain facilities were available, and it was the responsibility of industry to take some initiative. Larger companies might do it individually. Smaller companies, through their associations, could certainly consider what action they could take.

We are whole-heartedly in agreement with Mr. Golcher's suggestions of the ways in which the user might usefully tackle the problems which a new technique always raises. As a starting point the symposium itself may be said to have given the lead, and in view of the great interest aroused by it we are proud to have been the Association's collaborators in its organization.

SPARK-MACHINING SYMPOSIUM

THE SYMPOSIUM was opened by Mr. J. H. Swain, president of the NADFS, at the Botanical Gardens, Edgbaston, Birmingham, on September 16. The chairman of the first session was Mr. R. W. N. Danielsen, M.B.E., T.D., and of the second session Mr. W. E. Golcher.

The following papers were introduced and discussed:

(1) 'Characteristics of spark circuits,' by P. Farley, Birmingham College of Technology.

(2) 'History and development of spark machining,' by Dr. D. W. Rudorff, Director, Sparcatron Ltd.

(3) 'Electrode materials,' by J. L. Adcock, Wickman Ltd.

(4) 'Practical aspects of cavity sinking,' by G. H. C. Rhodes, Wickman Ltd.

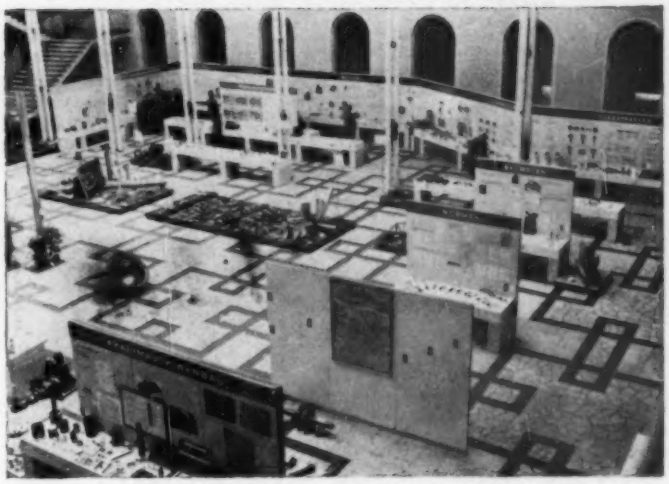
(5) 'Spark machining for industry,' by E. Cooper, British Motor Corporation Ltd.

(6) 'Metallurgical aspects and surface characteristics,' by Prof. Dr.-Ing. H. Opitz, Aachen Technical College, Germany.

Copies of these papers are available at 10*s*. 6*d*. a set from the Technical Officer, NADFS, Grove Hill House, 245 Grove Lane, Handsworth, Birmingham 20.

The complete papers, together with the synopses and discussions, will be published in METAL TREATMENT shortly.

An exhibition on all types of chipless forming was arranged this year in Germany, under the direction of Prof. Dr.-Ing. O. Kienzle, by the Hanover Technical College with the support of many organizations. This selective survey of the exhibition describes new methods and machines, many of which were being exhibited for the first time

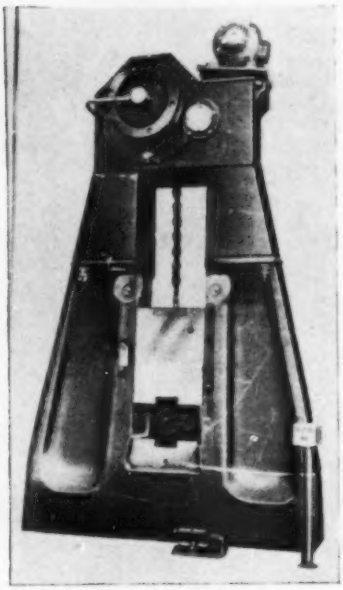


A survey of chipless forming

DIPL.-ING. W. BIEDERSTEDT and DR.-ING. H. MEYER

THE DESIGN ENGINEER of today is faced with a great variety of manufacturing processes and production techniques, according to which he can have his designs constructed. It is his responsibility to find and apply the particular process which will be the most suitable for his purpose, *i.e.* taking an overall view, that which will enable the work to be produced as cheaply and efficiently as possible. For many years now, the general trend of development has been to eliminate cutting, or machining operations, as much as possible and to obtain the ultimate form of the work piece by casting, sintering or plastic forming; reserving the use of cutting operations for the production of work to very close tolerances, unattainable by any of the other methods. Some fundamental knowledge of the features and limitations of the different processes is, however, essential if the designer is to apply them appropriately and correctly, since for every process and method, there are particular shapes which are most suitable, less suitable or entirely unsuitable for the particular kind of treatment envisaged. Furthermore, every process or method makes certain demands on the adaptation of the design, in principle and in detail, to the production methods to be used, and thus reflects on the ultimate form of the work piece; a casting must be differently designed from a forging for the identical purpose, and a machined part, again, is different from either, always assuming them to have been specially designed for that particular production method.

To inform designers of the possibilities offered them by the technique of chipless forming, an exhibition was arranged this year by Hanover Technical College under the title of ' Designing for chipless forming,' directed by Prof. Dr.-Ing. O. Kienzle, with the support of many professional organizations and industrial firms. In this exhibition were displayed all forms of chipless forming with the exception of sheet metal working. The techniques exhibited were: free forging, drop forging, upsetting and stamping, round swaging, roll forging, impact extrusion, hot extrusion and drawing. Since the designer requires to use these



1 *Chain-driven drop hammer*

techniques with understanding, the methods were described with the help of pictures, sketches, diagrams and samples, as well as the shaping process, the tools and the mechanical equipment used. It was also attempted to give an indication of the spheres of application and suitability of these different methods: the appropriate materials, the range of sizes and shapes, the attainable accuracy, the influence on material characteristics, and the economic advantages compared with other methods. Finally, on this basis, a number of rules for correct designing were illustrated.

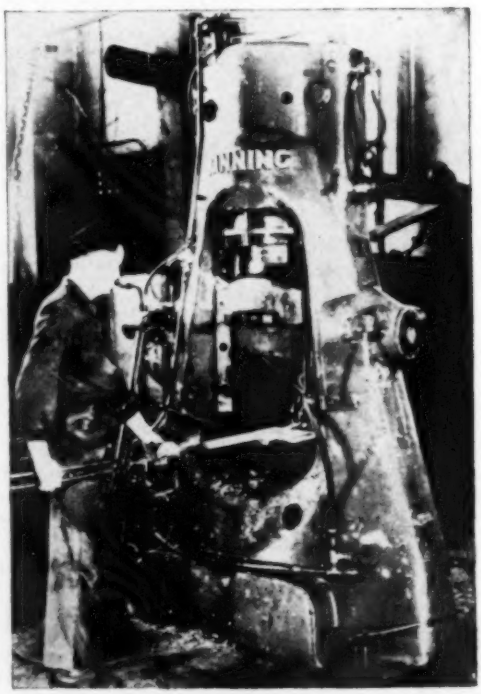
Examples were presented from a wide range of industrial applications, intended to show what components are suitable for production by chipless forming. The industries considered were: power plant construction, engine building, motor vehicles, aircraft, railway vehicles, shipbuilding, conveying and handling of materials, mining, electrical engineering, precision engineering, agricultural machinery, fittings, tools and jigs and, last but not least, machinery parts and components. Two stands dealing with the history of chipless forming and standardization problems completed the array of the exhibition.

Clearly, an exhibition intended principally for the benefit of engineering designers could only present the most elementary data and conclusions, which are common knowledge to the production experts. However, since the attempt was made to present the very latest state of the art, certain details or features were also of interest to the expert technologist, particularly as a general survey of the whole field of chipless forming and its applications was presented. Thus, cold-rolled turbine blades and gear wheels, and press-shaped internal threads were exhibited for the first time. In this article, these new methods, machines and finished work will be selectively described and discussed, while better-known methods will be disregarded.

Drop forging

From the bulk of its products, closed-die forging is, apart from the rolling of simple sections, the most important method of chipless forming, its versatility in shaping being unattained by any other process. Complicated work pieces of practically any metal, very nearly approaching the ultimate, finished stage, with a close grain and advantageous fibrous structure can be produced by drop forging.

The mechanical equipment of the drop-forging industry has been greatly perfected in recent years, and can now satisfy the increasingly stringent requirements in respect to quality and workman-



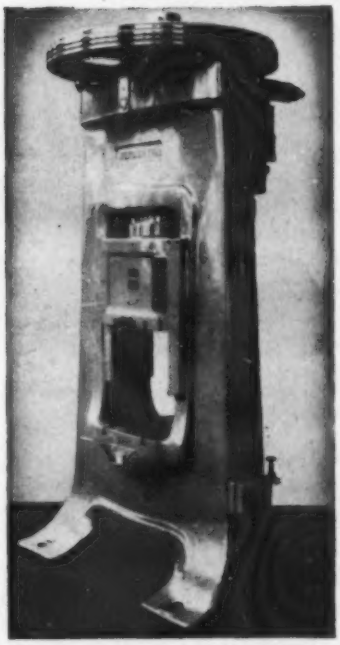
2 *Top-ram hammer*

ship of the forgings. Greater accuracy by the use of more rigid hammer housings and press frames, as well as substantially-constructed guides; higher output by quicker forging sequences; simplicity of operation by the extended use of hydraulic or pneumatic servo-mechanisms and programming controllers—these are the most important trends of present development in the construction of drop-forging equipment.

Thus, the anvil block and columns of the chain-driven drop hammer shown in fig. 1 are cast in one piece, and cannot shift under eccentric blows. The hammer is equipped with a friction-clutch and a winder drum. A profiled lifting cam ensures low acceleration at the beginning of the stroke. The guides have a multiple dovetail section at the bottom and a plain vee higher up, to reduce frictional losses. The guides are screwed to the columns, adjustability being sacrificed to rigidity. When the backlash in the guides becomes excessive, they must be removed for re-machining and refitted with shims behind the guides. The control voltage is applied by a programming gear to a terminal switch on the tup guide. When the rising tup closes the contact, the drop is initiated and the programming gear switches to the next step.

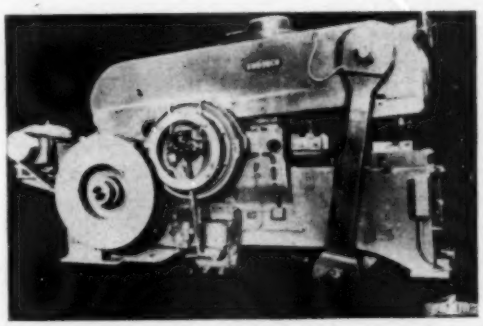
The top-ram hammer in fig. 2 has a completely enclosed housing with easy transitions between the cross-sections. The guide surfaces are arranged radially around the centre of the tup, so that the guide clearances do not change as the tup warms up. The number of blows per minute is infinitely variable between 80 and 120.

The flywheel screw press (fig. 3) also has a totally-enclosed housing reinforced by pre-stressed tie rods. The flywheel is driven by a friction gear; in later models, a toothed gear. The driven gear ring is, in this case, separated from the actual flywheel by sprung friction blocks. The ample bearing surfaces enable the flywheel to be accelerated without slip, but the gear can slip under a jarring blow.

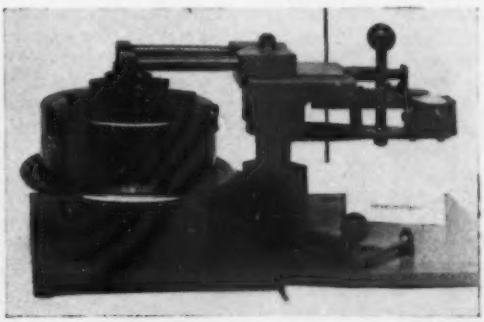


3 *Flywheel screw press*

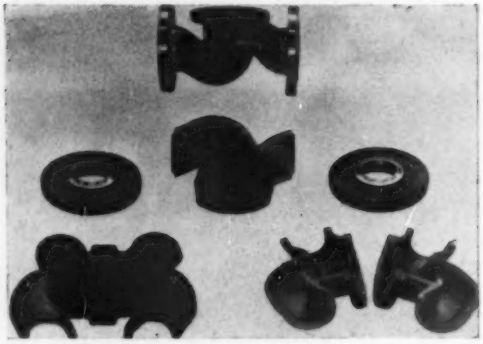
A horizontal upsetting machine of a construction which has meanwhile become standardized is shown in fig. 4. In this machine, the clamping jaws are split horizontally, the jaws working on the tongs principle. Two tie-rods on either side of the machine draw the top part of the machine with the clamping jaws downwards. The clamping force is adjustable by a handwheel. The easy accessibility of the tool space makes this machine particularly suitable for an automatic work feed, and thus for inclusion in automatically-controlled production lines.



4 *Horizontal forger with jaw grips*



5 *Drift (eccentricity) gauge for forged discs*



6 *Production sequence for a high-pressure valve, drop-forged, welded assembly*

These new machines can produce forgings of a dimensional accuracy considerably exceeding the values given in the standard specifications. However, the designer should not call for greater accuracy than is strictly necessary. Close control in the forge-shop will ensure that the quality of the work is maintained, for which purpose, special jigs and gauges are increasingly coming into use. The amount of eccentricity in disc-shaped forgings may be measured by the offset gauge shown in fig. 5. The part of the work piece forged in the bottom die is clamped in a rotatable, three-jaw chuck. The two arms seen above can be spread out to bear on the upper part of the work piece with rotatable end plates. Any offset or eccentricity of the centre between the ends of the two arms is recorded by the dial gauge on the right.

Economical and accurate forging work, however, requires that the work pieces shall be suitably designed for this technique. Among the design rules displayed at the exhibition was a diagram showing that liberal fillets should be allowed at all changes of section, in order to reduce tool wear and prevent the formation of flashes; another gave the minimum thicknesses of webs and fins, for forgings of steel and light alloy. The transformation of geometrical forms was also depicted, starting from the fundamental rules for the design of forged parts: side taper, ample fillets and gradual section transitions.

Welding of forgings

The welding of forgings to form large structural elements is becoming increasingly important, since modern welding methods allow of a standard of quality in the weld seams which after heat treatment is fully equal to that of the parent metal. By this means it is possible to produce work pieces which, because of their size or awkward shape, cannot be produced as a single forging. The valve in fig. 6 is welded together from two half-shells. These two shells are die-forged together from the same blank, in order to increase output and balance the side thrust. The halves are then parted by a saw cut and assembled by butt-welding. The shells are then secured in copper vice jaws, shaped to fit the half-shell and the flanges welded on the valve body. The result is a high pressure valve of the hydrodynamically good shape of a cast-steel valve, produced with all the advantages of the die-forging process. Additionally, there is a saving in material and time, compared with fully-forged valves which have to be finished by machining.

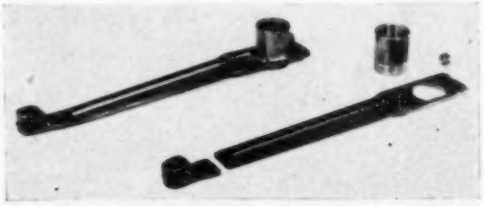
It is similarly possible to combine forgings with rolled sections. This is suitable in cases where the part has a suitable length of a cross-section which can be made by rolling, *e.g.* in locomotive connecting rods; in this case, only the ends are forged. Finally, forgings and sheet-metal parts can be combined (fig. 7).

Cold working

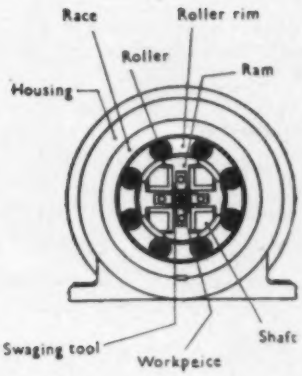
Whereas free forging and drop forging are hot-shaping processes, *i.e.* the material is worked above the recrystallization temperature, upsetting, coining, round swaging and, in some cases, roll forging and extrusion are cold-working techniques.

Upsetting and coining both as to the method and the features most important for the designer may be assumed sufficiently well known.

Among the as yet unfamiliar processes, we must mention *round swaging*. This enables the economical production of simple external shapes and, by swaging over a mandrel, a variety of axially-parallel or tapering bores with satisfactory accuracy (externally IT quality 13·11, internally IT 9-7); such as: internal splines, prismatic sections, coarse threads, internal teeth, etc., which can otherwise be produced only by tedious machining operations. As shown in figs. 8 and 9, the work piece is shaped by a number of pairs of swaging tools of simple shape, positively linked and moving coaxially and in unison towards each other. Suitable materials for round swaging are all carbon and alloy steels with a minimum



7 *Welded lever assembly of a drop forging (finished by machining), shaped sheet-metal parts, and turned components*



8 *All-round swaging: rotating swages controlled by fixed cams, work stationary*

elongation δ_{10} of 8%; also copper alloys, aluminium and other non-ferrous metals. The strain hardening resulting from cold-working in the surface layers, of a Vickers hardness between 230—300 kp./mm.², often makes a hardening heat treatment superfluous. The largest external diameter capable of cold-working is limited by the size of the machines at present available, to about 100 mm. diameter. For internal shaping, the wall thickness should not exceed 15 mm.

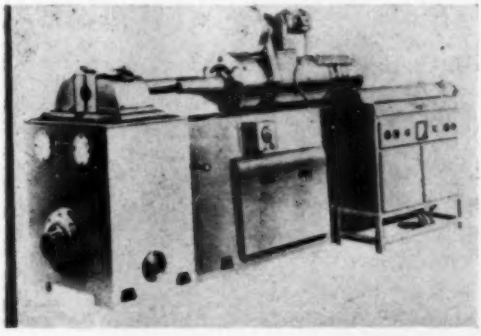
The forging heat reduces the resistance to deformation of the material, so that large reductions of area can be obtained with a single pass. The round-swaging machines used in this method are known as precision-forging machines. Low tool cost, long life, short production times and the high dimensional accuracy already mentioned, together with a good surface finish, all help to make the method very suitable economically.

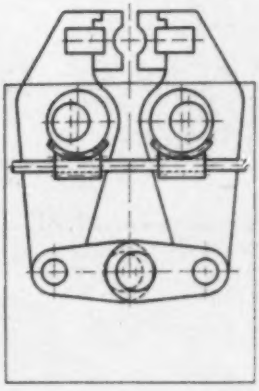
The advantage of *roll forging* techniques consists in the very low deformation forces involved. In addition to the standard sections, very many special sections can be rolled, but, owing to the high tooling costs, these are only economical for large production series.

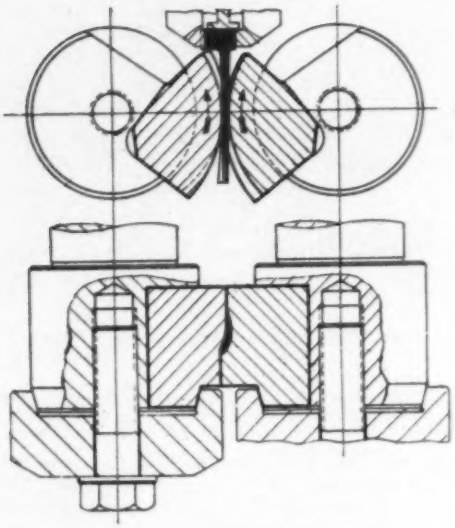
A very interesting process is that for producing long, narrow holes in hot-rolled bar stock. A hollow blank is used, a hardened, manganese steel mandrel inserted and the whole rolled out. Since the hardened, manganese steel has a higher coefficient of expansion than the material of the surrounding blank, the mandrel can easily be removed from the tube after cooling.

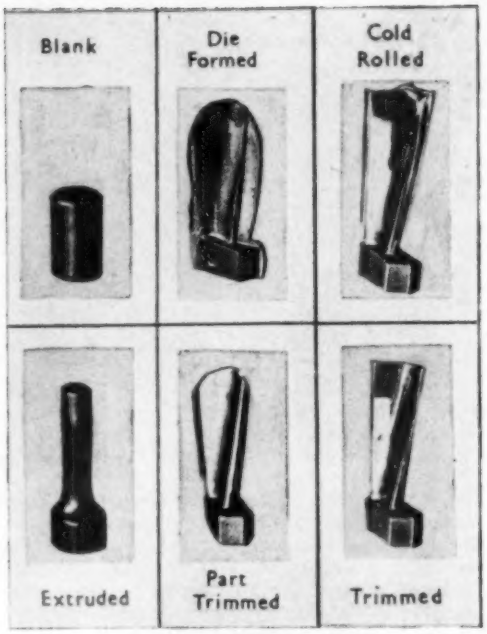
A novel application of the technique of producing work pieces of a longitudinally-varying cross-section is the *cold rolling of straight and warped*

9 *All-round swaging: non-rotating swages working radially, control by eccentrics; work rotates*





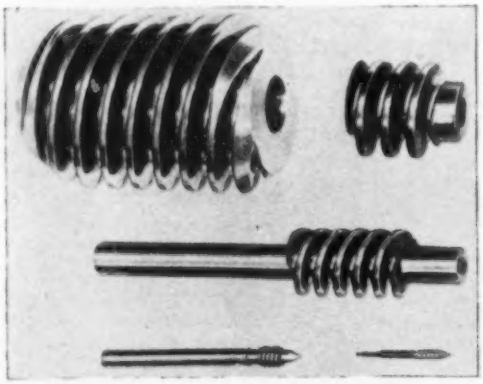




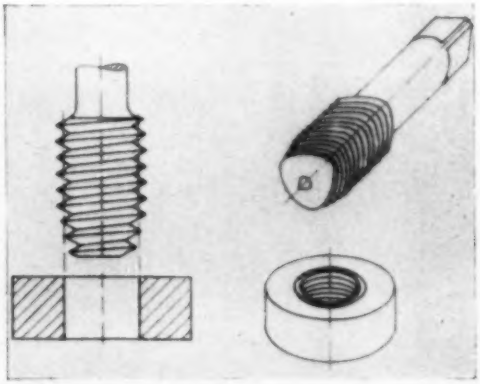
10 *Cold-roll forging of turbine blades*

blades, up to a length of about 400 mm. The starting blank is a suitable length of bar stock and an intermediate shape is obtained by extrusion and forging (fig. 10). The final form is imparted by cold-rolling, the required section form being obtained by grinding into the roll segments. These are mechanically or hydraulically forced into the blade root and are then rolled out according to the sketch. Strain-hardening and a good surface finish are characteristic of the turbine blades made by this novel and economical process.

The *cold rolling of screw threads* is gaining importance as against conventional machining or screw-cutting methods; since in view of the consequent high stressing of particular parts of the screw thread, an uninterrupted fibrous structure, increased hardness of the thread profile and higher fatigue endurance become of enhanced importance.



11 *Cold-roll forged threaded parts*



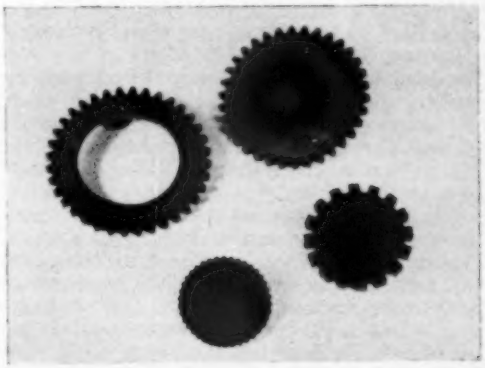
12 *Forming internal threads by chipless forming*

A generally known method is *flat rolling*, as used in the production of screws. The thread profile is milled or ground in the tool surfaces, to the required pitch, so that in the pass through the rolls, the work piece remains axially static during the pass, and a rolled thread can be obtained, apart from an end collar. In addition, circumferentially acting tools are often used. A distinction should be made between plunge-cutting, continuous and combined techniques. In the first case, the tool feed is purely radial, the tools bearing the thread profile in the same manner as the flat jaws of the preceding method. Here, too, it is possible to produce a continuous thread of a length not exceeding the roll width. In view of the high degree of accuracy attained, screw taps can also be produced by this method.

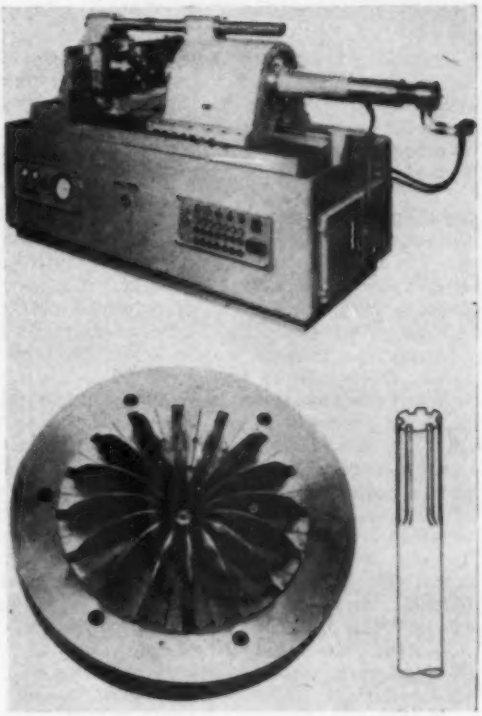
For long threaded lengths, the *continuous* method is used. In this process, the rolls are engraved with a zero-pitch thread profile. The pitch is obtained by swinging the rolls, which simultaneously performs the axial feed of the work. In view of the heavy displacement of the work piece material, the attainable accuracy is less than in the *plunge-cutting* method.

In the *combined* method, the thread profile is cut into the rolls with the proper pitch, somewhat smaller than the pitch of the work piece, so that only slight swinging of the rolls is necessary to produce the correct, ultimate pitch, and the accuracy of the method is, therefore, higher.

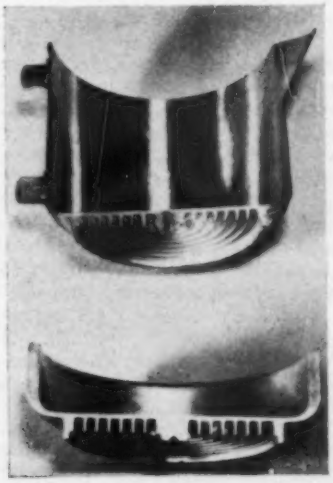
Fig. 11 shows a screw spindle with a maximum pitch tolerance of 0·13 mm. = 0·2%. The very short production times obtainable by the thread-rolling process are demonstrated by the cylinder of V2A steel shown on the right, which has a pitch of 225 × 4·5 threads to the inch, and was finished in 24 seconds. The same principle of thread rolling can also be applied to the production of ribbed



13 *Cold-roll forged spline sections and gear teeth*



14 *Machine and tools for cold-roll forging splines and gear teeth*



15 *Press-shaped work piece produced from machined blank in foreground*

(gill) tubing with helical fins, of copper or aluminium alloys.

A remarkable new development is the *shaping of internal threads* (fig. 12). Contrary to the usual screw taps, the tool in this case has no cutting edges but has a cross-section of uniform thickness. Consequently, the tool is easy to make. This method makes standard threads from M3 to M72 × 2. Suitable materials are aluminium and (soft) aluminium alloys, as well as steel up to 45 kp./mm.² hardness. The increase of about 20% in the shear strength due to work-hardening often enables a smaller size of thread to be used. Additional advantages are: no roughing cuts, no breaking of the tap edges, no chips (this is found particularly advantageous in blind holes); while galvanized surface finishes are in part preserved.

A very new and interesting roll forging technique is the *cold rolling of splined sections* and *gear teeth* (fig. 13). These sections are not produced by a radial feed but by lengthwise rolling, using a roll such as shown in fig. 14. The tool consists of a round core carrying axially-rotating discs the edges of which are profiled to the required shape; the resulting rolled profile can even be an involute curve. The finished gears are obtained by parting from the bar stock, and, with a surface roughness not exceeding 3 microns, require no further finishing on the tooth flanks. Here, again, a satisfactory fibre structure coupled with work-hardening make this method of increasing importance.

Stretch rolling between a pressure mandrel and a pressure roll is another rolling technique in which the blank is drawn down and stretched stepwise. In this method, the high economy of material compared with machining and the consequent reduction in production costs make themselves felt even in short production runs. The finished part represented in fig. 15 has been produced from the intermediate blank shown below by stretch pressing.

Finally, *micro-smoothing* by planishing rolls may be included in the same group. This process can be differentiated according to the purpose in view; either, the improvement of already worked surfaces; or, the work-hardening of particularly highly-stressed parts of the work. In either case, only a thin, surface layer is involved. Thus the hardness at 0·01 mm. under the surface can be increased, for instance, in cast-iron, from a value of 260 to 400 kp./mm.² Vickers hardness and at 0·5 mm. from 260 to 280 kp./mm.²

Extrusion

Extrusion, whether cold or hot, is a forming method in which the material is forced by a punch through a die opening, which imparts the required shape to the work piece (blank). Variations of the method are forward extrusion, in which the material flows in the same direction as the punch, reverse pressing, and a combination of the two. The materials suitable for extrusion are those which have a high elongation, low yield point, and low resistance to deformation. A further important factor is the yield curve, the development whereof determines the strength of the material after shaping. By varying the degree of deformation in the individual passes, it is possible to obtain varying degrees of strength.

Suitable materials are listed in Table I. The suitable work piece shapes are principally unsym-

TABLE I *Suitable materials for extrusion*

COLD	HOT
Non-ferrous metals	
Lead	Zinc
Tin	Copper
Zinc	Copper Alloys
Copper	*e.g.* Ms 58
Copper Alloys	↓ (~ 600°C.)
e.g. Ms 70	Ms 60
↓	Ms 67
Ms 85	↓ (~ 550°C.)
Aluminium Alloys	Ms 70
e.g. AlMgSi	Aluminium Alloys
AlCuMg	*e.g.* AlMgSi (~450°C.)
AlMg 3	AlCuMg (~ 450°C).
AlMg 5	AlMg (~ 450°C.)
Steels	
SM-steel, rimmed (open-hearth) cast with C < 0·2% (if. req. ~ 0·4%)	Carbon steels with C < 1·5%
SM-steel, killed (open-hearth) cast with C < 0·4% low-alloyed with Si, Mn, Cr, Mo	High-alloy steels with Cr, Mn, Si, Ni, Mo [~ 800°C. (low heat) to ~ 1,200°C. (full heat)]
Basic-Bessemer steel with C < 0·1%	

metrical solid and hollow shapes with parallel envelope surface; but, equally, unsymmetrical shapes with head, shank and body parts, and bottoms of varying conformation. The length of the cold-extruded shank should not exceed fifteen times the starting diameter. The size of the work pieces which can at present be produced by cold extrusion is from 15 to 1,200 mm. length or height and from 5 to 140 mm. external diameter. Wall-thicknesses of 0·5 to 15 mm. and similar changes in the wall thickness of an individual work piece are possible. Noses, shaped projections or depressions and lettering can be pressed in or on to the bottoms in the same working pass. These may be symmetrically or asymmetrically arranged. Sizes attainable and economically favourable output numbers are listed in Table II.

The allowances attainable are between IT 12 and 9; in exceptional cases, IT 8 to 6. Close

TABLE II *Dimensions for extrusion*

	Cold-extrusion		Hot-extrusion
	Steel and ferrous alloys	Non-ferrous and light alloys	Steel and ferrous alloys
Diameter up to	150 mm.	400 mm.	250 mm.
Min. wall thickness ..	0·3 „	0·07 „	2 „
„ „ „ ..	0·07 D	0·01 D	0·2 D
Min. bottom thickness ..	1·5 mm.	0·5 mm.	2 mm.
„ „ „ ..	0·1—0·2 D	0·05—0·1 D	0·06 D
Weight up to	5 kg. (G'many) 135 kg. (U.S.A.)	20 kg.	50 kg.

Tolerances: All tolerances are so ample that if exceeded the piece is, in fact, useless.
Dimensional allowances: Usual IT 11—6 tolerance limits. Special IT 8—6 if required.
Axial unsymmetry (tubes): 0·5 to 1·2% of diameter.
Eccentricity: 0·2—0·6% of diameter.
Obliquity (skewing) of holes and mandrels: Depending on length and diameter.
Economic Piece Numbers (numbers off): Empirical rule numbers.

0·001	—0·02	kg. ea.	—10,000
0·02	—0·5	„ „	5,000
0·5	—10	„ „	3,000
10	—35	„ „	2,000—10,000

Example: For 12 kg. approx. piece weight, tooling costs about 7,000 DM.; for 0·2—0·4 kg. pieces, 200 to 3,000 DM.

These rule numbers require to be modified according to shape of piece, surface finish required, or close tolerances.

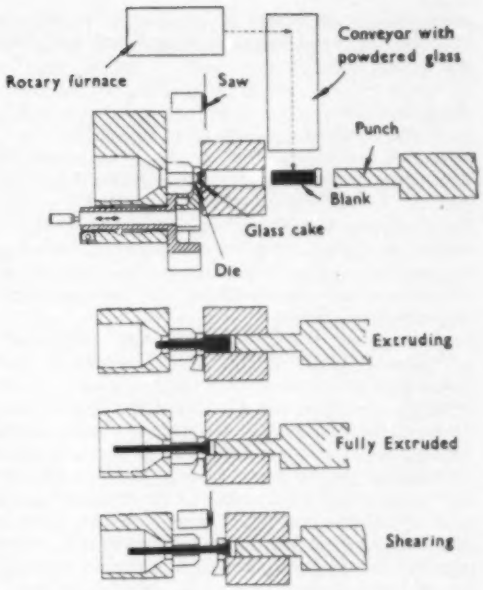
allowances involve a shortening of the tool life; it should consequently be verified in the particular case whether oversize pressing with ensuing drawing or machining, *e.g.* centreless grinding, is not preferable.

The eccentricity or degree of offset of the external diameter with reference to the internal diameter is, according to the particular method used, between 0·5 and 1·2% of the wall thickness; the ovality about 0·2 to 0·6% of the external or the internal diameter.

Despite the variety of forms which can be produced, the designer is restricted in some way, in the design of parts for extrusion.

Extrusion can be a hot-forming process closely akin to cold extrusion, except that larger quantities of the starting material are used, so that section lengths up to 25 metres can be obtained.

The overall section dimensions depend on the developed power of the available presses. The presses up to 8,000 Mp. available in Germany enable the extrusion of light-alloy sections with a circumscribed circle of up to 420 mm. diameter. In particular cases, this limit can be exceeded by



16 *The extrusion of steel*

bending vee or circular sections; stepped sections are also possible.

The variety of section forms made possible by the versatility of shape of the extrusion die has enabled many sections to be produced by plain extrusion, which had hitherto only been obtained by riveting, welding or the like. The appropriate materials are aluminium and aluminium alloys, magnesium alloys, copper and copper alloys, zinc and zinc alloys, tin and tin alloys, lead and lead alloys, and also any hot-workable steel.

The extrusion of steel sections was first made possible by the invention of the Ugine Sejournet process which, by the use of molten glass, overcomes the difficulty in obtaining high plastic workability of steel owing to its inherent, high mechanical strength, and the necessity for very high working temperatures. The heated blank or billet is rolled in powdered glass and a cake of glass placed in front of the die opening in such manner that, upon extrusion, a lubricating and insulating coating of molten glass is formed on the metal being extruded (fig. 16). When the extruded section cools, the glass coating bursts off. Steel sections unsuitable for rolling owing to the small quantity required can now be economically produced by extrusion, in view of the relatively low cost of production of the dies. The designer should bear in mind some essential points in the design of section forms for

extrusion, in order not to burden the production cost by the need for complicated and expensive die forms.

Applications

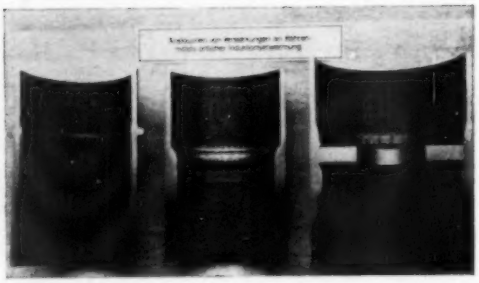
At the exhibition, examples of the application of extrusion techniques were shown. These included machinery parts, engine parts, aircraft and motor vehicle components, railway construction, ship building, mining, the conveying and handling of materials, fittings, precision engineering, electrical engineering, structural components, and tools; separate stands for standards and historical data complete the display.

Among the *machinery parts*, cold roll forged screws were dealt with in detail, owing to their great importance for engineering. A screw strain diagram indicated the suitability of titanium as a material for screws. The advantages of cold-shaped screws are the reduced notch effect due to more favourable fibrous structure and the influencing of the strength of the material in different cross-sections of the screw by suitable arrangement of the working passes or stages in the shaping. It will be obvious that in this regard, the starting diameter of the screw stock is of considerable importance.

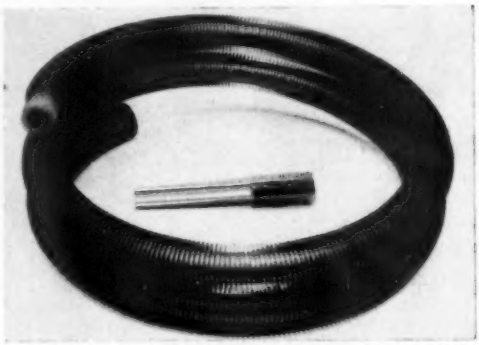
Tubes can be produced by hot or cold forming with internal or external ribs or swellings. By upsetting, flanges can be formed, by round swaging, tapered and cylindrical stepped sections, or any form of internal section by swaging over a mandrel. The reinforcements on the tubes represented in fig. 17 have been produced by local induction heating followed by the application of pressure in the direction of the tube axis. One possible application is the forming by upsetting of reinforcing rings on high-pressure containers, the bursting strength of which can be increased by this means. By moving the induction coil along the tube, reinforced walls of considerable length can be obtained. The method also enables discs (diaphragms) to be fitted into tubes.

In addition to the well-known finned or gill tubes with the fins welded or soldered on, gill tubes can also be made by the screw-thread rolling operation already described, out of a single blank (fig. 18). By virtue of the unhindered heat flow, such tubes have a particularly high thermal conductivity. They are obtainable in lengths up to 3 metres, with ribs up to 12 mm. deep, in light alloy (3·5 mm. in copper).

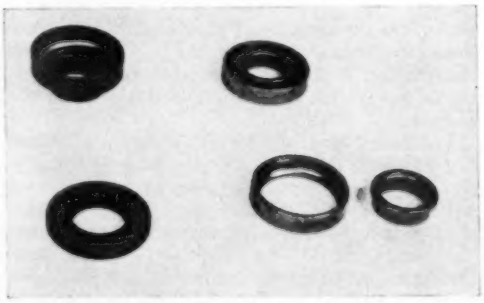
In addition to the usual methods of making roller bearing races by free forging or upsetting, punching and roll forging, or simple upsetting and punching, a patented method has been made public in which the inner and outer races are made in one operation by extrusion (fig. 19). The starting blank is shown in front on the left, and behind it, the finished shape



17 *Upsetting reinforcing beads on tubes*

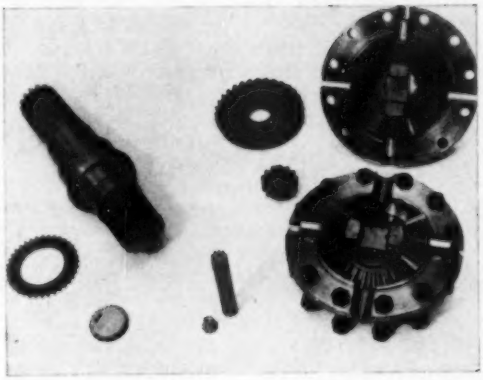


18 *Cold-roll forged gill tube*

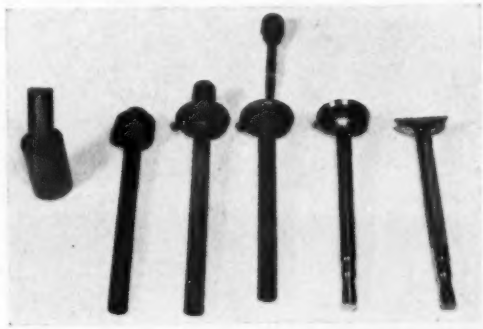


19 *Extruded roller bearing races*

obtained by die pressing. The inner and outer races are then parted. However advantageous this process may appear to be, it has the drawback that heat treatment of the race rings is still necessary, which must then be followed by grinding. The method can serve as an example, however, for cases in which heat treatment can be dispensed with. Roller bearings are akin to the ball-and-socket joints used, for instance, in motor vehicle trailers.



20 *Gear wheels made by plastic shaping:* LEFT *cold-rolled gears (parted from stock bar);*
CENTRE FRONT *extruded gear section and pinion;*
RIGHT *hot pressed wheels and differential gears for tractor*



21 *Production sequence for an extruded hollow valve casing*

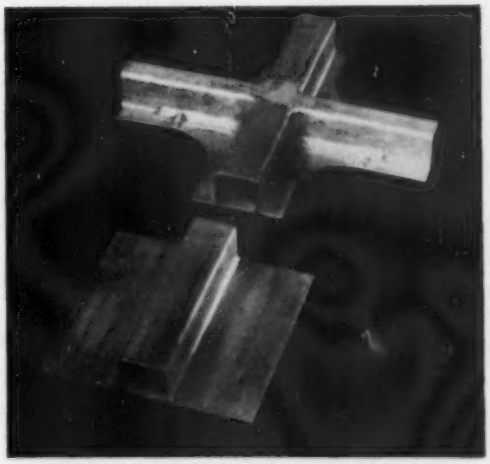
Gear wheels can be produced by plastic (non-chipping) forming, in four different ways: by cold-pressing, cold roll forging, hot forging, and extrusion. The last-named method can be used for gears of light alloy or brass, provided no great accuracy is required. The wheels are then parted or cut off from the profiled bar (fig. 20, middle).

Hot-forged gear wheels can be used in the less highly-stressed gears of agricultural machines and tractors. For machining the central bore, the gear wheels are clamped in a toothed jig. Hot extrusion is economical for production series of 500 pieces or more, particularly for wheels with additional lugs or projections, or for gears without a proper run out for the miller or cutter.

In *engine building*, a great number of plastically formed components can be used: crank- and camshafts, connecting rods and rocker arms can be made by drop forging; valves by upsetting or extrusion; gudgeon pins and accessory parts for injection pumps by extrusion, to name only a few examples. Crankshafts can be drop forged for sufficiently large production series, and unit weights not exceeding about 1,000 kg. Larger shafts, and smaller items in lesser numbers are shaped by free forging, or assembled from drop forgings by welding or shrinking.

An important point in regard to finishing treatment is the proper balancing of drop forged crankshaft components which are only to be partially machined. If centring is purely geometrical, the unbalance of the parts left rough-forged is not eliminated. The forging must therefore be balanced and centred after balancing. This, however, can be done in a more suitable manner. In machining, then, more material is removed from one work piece than from another, *i.e.* after machining, the work has to be balanced again. Consequently, 10—20 shafts from the same batch are suitably balanced to zero unbalance, then centred and finished by machining. The remaining degree of unbalance is then determined, and the balancing machine adjusted accordingly. The remaining forgings are then balanced accordingly, leaving the machine with a determined degree of unbalance which, however, is eliminated by the succeeding machining operation. A prerequisite for this technique is that the forgings must be identical, *i.e.* forged in the same die. All forgings made in one die must therefore be kept together in the same batch.

An interesting process is the production of hollow valve elements by extrusion (fig. 21). A blank



22 *Light-alloy welded framing of a coach body rear end*

23 *Casing for a railway vehicle coupling:* LEFT *drop-forged half-shells*
RIGHT *welded casing*
FRONT *drop forgings for the coupling mechanism*

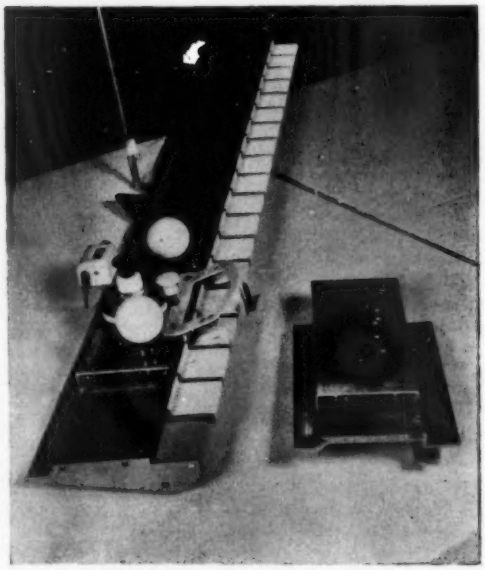
24 *Forging from different directions simultaneously (a fitting with undercut parts)*

partially pierced from one end is used, into which a mandrel is inserted, with a surface prepared by sealing. The two are then heated together and pressed through a die. The film of scale prevents the two elements from welding or sintering together, so that the mandrel can be withdrawn after pressing. A ring of highly heat-resistant steel is then fitted round the valve head, which is welded on by heating. The resulting, reinforced valve head is shaped in a press and after the bore has been welded up, finished by grinding the valve seating surface. The wall thickness of these valves is highly uniform, while, if the hollow is bored out, the boring bit may easily become out of alignment, as a consequence, heat transmission is irregular and the valve warps unsymmetrically.

Small valves can also be made by cold extrusion and upsetting in a bolt-bending machine. Larger sizes can either be made in the horizontal upsetter or in an electric upsetting machine, followed by finishing in a Vincent press. In the electric upsetter the bar is clamped between two copper jaws and pressed hydraulically or pneumatically against a swage-plate. The end of the stock bar between the jaws and the swage plate is heated electrically. When forging temperature has been reached, the bar is pushed forward by the copper jaws and the heated end upset. Since the work feed is continuous, a very large volume can be upset without the bar buckling or bending, as may happen in an ordinary swager, when the ratio of unsupported length to diameter becomes excessively large.

Turbine blades can be drop forged as well as roll forged. In this process too, degrees of accuracy are now obtainable which only require finishing of the blade profile by fine grinding. The saving in material and working time compared with milling is considerable. Straight profiles are first forged and then drawn, the accuracy attainable making any finishing operations superfluous.

Since plastically worked components ensure the best possible economy of material by virtue of their favourable fibrous structure, compact and pore-free grain, and the strain-hardening effect of cold working, such parts are increasingly used in vehicle construction, in which the highest strength for the lowest weight is important. Thus, 29% of the total weight of a motor car front axle consists of drop forged parts, 2·7% are cold swaged and 29% assembled from sheet and tube stock. For fittings and bodies, light alloy forgings and extruded



25 *Hand knitter built up of extruded sections*

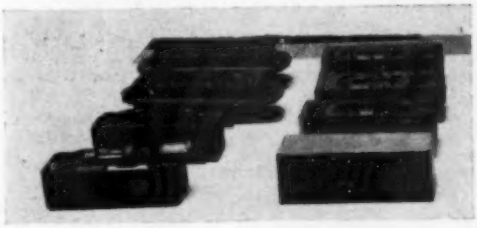
sections are being increasingly used. Fig. 22 shows a bracket assembly for the rear end of a coach or bus body.

In addition to the manifold possibilities afforded by the direct use of extruded sections, the designer can have further recourse to the operations of joggling, bending and seaming (jointing or mating) section bars. Thus, sections can be notched or cut away, to form joints; the lines of force then running undisturbed, longitudinally through the main bearers.

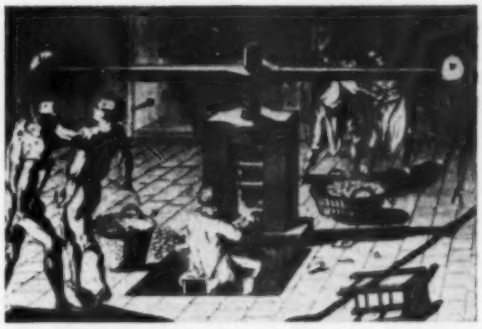
In the construction of *railway rolling stock*, light alloy extruded sections are also being increasingly used, *e.g.* for the framing of railcar body sides, for sliding roofs on goods vehicles and for the windows of passenger rolling stock. Fig. 23 shows a casing for a Scharfeuberg coupling, which not only automatically performs the mechanical coupling of two vehicles but also automatically makes the electrical and hydraulic (pneumatic) connections between them. The casing is assembled from a number of drop forged partial shells, by welding. Buffer sleeves and shanks are made by hot die pressing.

In *aircraft construction*, drop forgings and extruded sections are used to a very large extent. A large aircraft contains up to 900 different forgings which in the finished state weigh nearly 2½ tons. In America, extrusion presses up to 12,500 tons and hydraulic forging presses working at 25,000 and 50,000 tons press load are in use. The modern integral form of construction for supersonic aircraft calls for thick-walled, inherently rigid fuselage shell plates, which can be made by extrusion or drop-forged. Compared with production by machining, very great savings are possible. Drop forging the skin panels for aircraft wings saves 75% of the material, compared with machining. In another case, 41 components had formerly to be assembled by means of 24 bolts and 1,045 rivets.

In *mining engineering* the favourable conditions afforded by the use of light alloy extrusions enable savings in the weight of many items of equipment to be obtained. Pit props and frames, pusher rams and conveyors may be instanced, in which extruded



26 *Production sequence for hot stamping*



27 *Eighteenth-century coining shop*

sections can be used in conjunction with drop forgings. On the other hand, mine equipment includes many items, solid-shaped from steel; *e.g.* mechanical coal picks built up entirely of forged parts and mine frames consisting of rolled sections assembled by drop forgings.

The *handling and conveying of materials* involving heavy link chains and conveyor rollers also offers wide perspectives for forging techniques. Extrusions are, however, also used. Thus, the framing of a ropeway gantry with 10 travellers has been welded together from extruded, light alloy tubing. Hoist platforms, ladderways and the bottoms of conveyor trucks or skips have also been fabricated from extruded sections.

Small fittings are often made of copper alloys by hot pressing when, if complicated shapes in which it is difficult to obtain a proper distribution of the material are required, the starting blank can be cut from an extruded bar of suitable cross-section. By suitable shaping of the blank, the amount of machining to be done can be reduced to an absolute minimum. A new press of British manufacture enables forging to be done in several different directions simultaneously (fig. 24).

Electrical engineering also offers many opportunities for using parts shaped from the solid: these include extruded condenser pots, drop-forged trolley wire clips, switching cams, gas-pressure switches and grooved tubes for the hydrogen-cooling systems of generator units, fabricated of extruded and drawn sections, also generator rotors made of freehand forgings and the like.

Extruded sections in *precision mechanics* form the starting material for the economical production of watch and clock cases, lens setting rings and keyhole sections. Stampings of small dimensions are used in the photographic industry, as discs for film counters, small gears, nameplates, etc. In sewing machines most of the parts are forged, with a few drawn and extruded components. An impressive

example of the accuracy with which extruded sections can be made is shown in fig. 25. In the hand-knitter represented, three different section shapes are used, for the base plate, the guide bar and the locking mechanism.

In *structural engineering* extruded sections enable the architect and the engineer to design 'ideally' according to the best principles of building construction, statics and architecture. Sheathing sections are combined to form attractive pillars and corner mouldings; window and door frames can be supplied in any shapes; extruded sections are also used in the manufacture of builders' hardware and in bridge construction.

Of the forming methods used in *toolmaking* mention can be made of hot and cold die stamping, *i.e.* the production of forming tools by forming methods. Cold stamping, first used to make press dies for the plastics industry, since repeat patterns are required in a single die block, is now also used for making forging dies. Shallow die patterns of not too large a size are the most suitable for this technique, although even fairly deep patterns can now be stamped. For cold swaging very high press loads (up to 2,000 tons) and very low ram speeds (0·1—2 mm./min.) are required. Hot stamping, on the other hand, requires no special machinery but is inferior to cold sinking in regard to accuracy and surface finish. The master die (fig. 26, left front), which is made with shrinkage allowance, is in this case struck on a die matrix heated to forging temperature. The master and matrix are held in special fittings. The stamping face of the matrix die is ground flat (fig. 26, right front) in order to obtain a high surface finish in the stamped die. For the same reason, this surface must be protected from scale formation during heating and stamping. The stamped pattern, including the flash pocket, is so accurate that no finishing is necessary, only the burr on the matrix requires grinding off. Fig. 26 in the background shows the finished dies.

Recessed press dies (matrices) are more economical for two reasons: it is usually cheaper to make the master die stamp in relief, than to make a recessed master. This is particularly the case for master dies which can be turned in a lathe and then parted off. Secondly, recess stamping is usually much cheaper than milling a sunk pattern since only one die needs to be made. The advantage is the greater the larger the number of dies which can be made by one relief stamp.

Historical note

The history of plastic (non-chipping) forming is centuries old. Native gold was the first metal to be so worked, next, some 3,000 years ago, bronze castings. The first record of the making of wrought steel in the forging furnace is from the East in the year 3,000 B.C.; the first production of steel from blast furnace pig iron, followed by open-hearth refining dates back to the 12th century B.C. Between 900 and 500 B.C. steel displaces bronze. The art of coin stamping (fig. 27) promoted the development of cold-forming between precision dies.

Metallurgy courses

Kingston Technical College

Special courses for the session 1959-60

1. *Chemistry and metallurgy of rarer metals.* Eight lectures given by specialists from industry. Tuesday evenings, commencing October 20, 1959.

2. *Principles of corrosion and protection of metals.* Eight lectures given by G. Isserlis, B.SC., A.I.M. Thursday evenings, commencing October 22, 1959.

3. *Metallurgy and semi-conductor devices.* Six lectures given by A. S. Abrahams, M.A.(CANTAB.), A.I.M. Tuesday evenings, commencing January 5, 1960.

4. *Corrosion problems in the aircraft industry.* Six lectures given by specialists from industry. Tuesday evenings, commencing February 16, 1960.

5. *Technology of copper-base alloys.* Six lectures given by specialists from industry. Thursday evenings, commencing February 18, 1960.

Wolverhampton and Staffordshire College of Technology

Advanced short course

Fundamental requirements in the selection of steel. Eight lectures to be given on Tuesday evenings from 7-9 p.m., commencing September 22, 1959. Lectures still to take place as follows:

5. *The influence of mechanical properties on selection.* A. D. Hopkins (College of Technology, Birmingham). October 20, 1959.

6. *The effects of manufacture on the properties of steel.* E. Johnson (William Jessop & Sons Ltd.). October 27, 1959.

7. *Steel choice and production techniques.* E. Mitchell (Joseph Lucas Ltd.). November 3, 1959.

8. 'Your questions answered' by a panel of lecturers. Chairman: G. R. Morton. November 10, 1959.

Post-graduate and short course, metallurgy.

2. *Ternary systems in metallurgy.* Eight weekly lectures on Thursday evenings, 7-9 p.m., commencing October 15, 1959. Lectures: G. R. Morton and others. Course tutor: D. R. Cliffe.

3. *The metallurgy of deep drawing and pressing.* Eight weekly lectures on Tuesday evenings, 7-9 p.m., commencing November 17, 1959. Course tutors: D. R. Cliffe, G. R. Morton.

4. *Iron and steel reviews—Fifth Annual Lecture Series. The manufacture of steel tubes.* Eight weekly lectures on Tuesday evenings, 7-9 p.m., commencing January 26, 1960. Course tutors: G. R. Morton, H. Southan.

5. *Fundamental requirements in the selection of refractory materials.* Eight weekly lectures on Tuesday evenings, 7-9 p.m., commencing March 22, 1960. Course tutors: J. C. W. Davies, G. R. Morton.

Hot working of alloy steels

Part 3 Influence of structure and composition

A. GUEUSSIER and R. CASTRO

This investigation into the hot ductile behaviour of alloy steels of varying compositions under varying conditions was described by the authors at the 1957 *autumn meeting of the Société Française de Métallurgie, Paris, and published in French in 'Revue de Métallurgie,'* 1958, **15,** (11). *The authors are both with Aciéries Electriques d'Ugine, Savoie, France, Mr. Castro being chief engineer, head of research. This is the third and concluding part of the study*

Influence of structure

Many authorities have already shown that two-phase structures frequently show hot ductility lower than with homogeneous structures. It is definitely known that the presence of a certain amount of ferrite in austenitic steels can lead to difficulties in working.[6, 15] To illustrate this fig. 18 shows the appearance of bend test-pieces taken transversely to the surface of 10 kg. (22 lb.) ingots with analyses as given in Table II (a). These casts of stainless steel had chemical compositions chosen so as to give structures ranging from pure austenite to pure ferrite passing through the whole range of intermediate two-phase structures. The percentage of ferrite present in the steel as cast is shown for each of them. Fig. 19 shows results obtained from tensile tests on another series of casts with varying structures (Table II (b)),* after forging down into $\frac{1}{2}$ in. square. This diagram relates the hot ductility to the structure present in each case at the moment of deformation of the steel, as found by micrographical examination of the zone of fracture of each test-piece. The curves obtained correspond with four different test temperatures.

It will be seen from the two previous experimental examples that the ductility of the whole of the structures studied passes through a minimum when the amounts of ferrite present are of the order of 20 to 40%. It will also be observed that, starting from pure ferrite and pure austenite, the appearance of a growing quantity of a second phase is accompanied by a large reduction in ductility.

The same phenomenon can be illustrated by studying a 12% Cr steel, forged and annealed. In fig. 20 will be found the variation in hot ductility of this steel as a function of temperature, as shown by hot tensile tests. The graph so obtained has two minima. A micrographical check test has shown that these minima occur within the ranges of temperature in which the metal has a two-phase structure. It is indeed known that, in these steels, the structure, which is entirely ferritic in the annealed condition, changes, when the temperature is raised, into a homogeneous gamma phase, and then into a homogeneous delta phase before melting. These changes lead, at intermediate temperatures, to two-phase structures, alpha + gamma for the first minimum, and gamma + delta for the second. This example shows again the reduction in ductility which takes place in an alloy from the appearance of a two-phase structure.

Influence of chemical composition

Numerous examples have already been given of the influence of the chemical composition of alloy steels on their hot ductility.[16] Apart from the specific role of certain added elements, insistence has often been made on the part played by small amounts of certain impurities in the hot working of certain steels. One might recall the specific role of oxygen and sulphur in the hot-shortness of mild steels, [17, 18] the harmful effect of tin in low-alloy steels,[19, 20, 21] and that of lead in austenitic steels of the 18/8 type.[22] The authors have shown the last example by hot tensile tests, of which the results are given in fig. 21.

Investigations into the role played by chemical composition on the hot ductility of steels often leads to complex results, of which the conclusions drawn may vary according to the experimental conditions adopted, and the statement of such

*See September issue for Tables, page 324.

results then risks becoming wearisome. To throw light on this question, the attempt has been made to link up the influence of additions on the various characteristic physical phenomena which can be produced at high temperature in steels and which govern to a large extent the laws of hot ductility. Three typical examples may be given showing the influence of different elements on the phenomena of burning, precipitation and recrystallization.

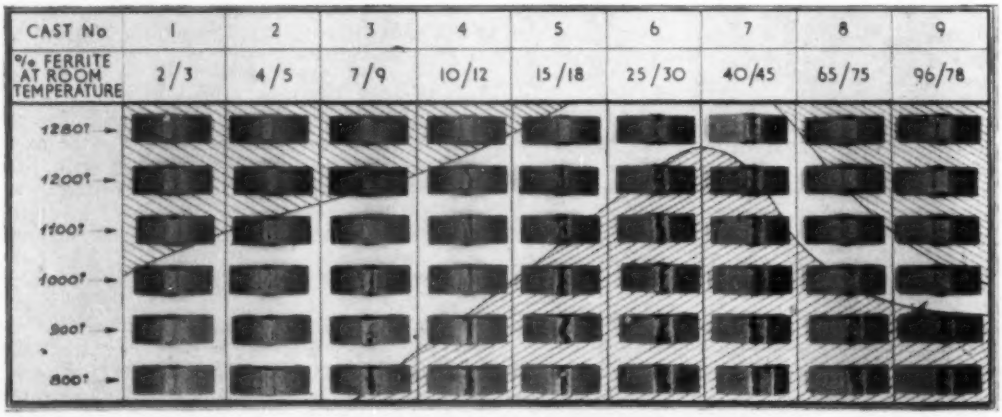
Phenomenon of 'burning' Any element which reduces the solidus temperature of a steel on the equilibrium diagram reduces similarly the temperature of burning of the steel. But certain elements or impurities, in small or moderate quantity, can reduce appreciably the temperature of burning by causing, through segregation at grain boundaries, the formation of phases or eutectics with low melting points.

A characteristic example of this phenomenon, fig. 22, shows the influence of an addition of 0·05% boron on the hot ductility of an 18/8 type of steel. The large drop in temperature of burning seen in this case is the result of the presence of a eutectic rich in boron. This harmful effect must be distinguished from the favourable influence of this element[23] on deformability at temperatures below burning point.

A similar phenomenon of premature burning, more or less pronounced, can be seen in the same steels with sufficient additions of S, Ph, Zr, Nb, and this is also explained by the presence, at high temperatures, of intergranular meltable phases. It will be noted that the observed changes are generally greater in the steel as cast, owing to the phenomena of primary segregation which take place during solidification of the metal and which are reduced later by the homogenizing effect of plastic deformation whilst hot.

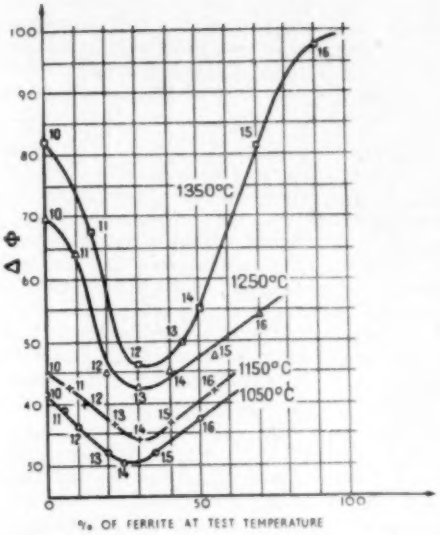
Phenomena of precipitation In steels with a homogeneous austenitic structure while hot (stainless steels and low-alloy mild steels), there is often observed, as previously shown, at moderate temperature between 900 and 1,100°C., a brittleness effect which is all the more pronounced when the speed of deformation is lower. The authors have already studied this phenomenon in detail for austenitic 18/8 stainless steels.[10] It has been shown, in particular, that this phenomenon is tied up with the precipitation of carbides during the actual process of deformation. It increases in intensity with the carbon content and with the temperature of preliminary quenching, and it can be reduced, or even eliminated, by carrying out a prior precipitation of carbides before deformation. Finally, it has been shown that the addition of stabilizing elements, such as titanium or niobium, has the essential effect of delaying the entry of carbon into solution and of reducing the speed of carbide precipitation. By this procedure, the stabilizing elements can, under certain conditions, other things being equal, reduce the brittleness phenomena observed in austenitic steels.

Similar brittleness phenomena have been revealed in mild and low-alloy steels. They are intensified with the addition of an increasing quantity of aluminium during final deoxidation. This fact is shown in fig. 23, which relates to a chrome-molybdenum steel to which increasing amounts of



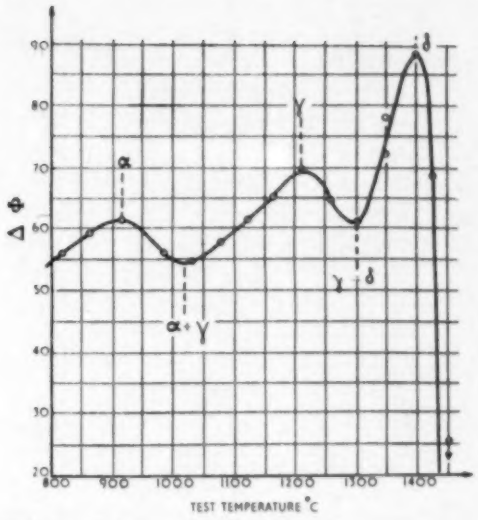
18 *Influence of structure on hot ductility of austenitic seels with varying proportions of ferrite*

Hot bend tests: metal as cast taken from nine ingots (22 lb.). Deflection $\frac{1}{8}$ in. Water quenched 1,050°C./1 h.
Speed of deformation 20,000%/sec.
Upper hatched area corresponds to the zones of temperature and initial contents of ferrite, for which working is possible without cracking. Lower hatched area corresponds to a zone where plastic working is impossible or very difficult. Intermediate band corresponds to a zone where working is possible, but under poor conditions



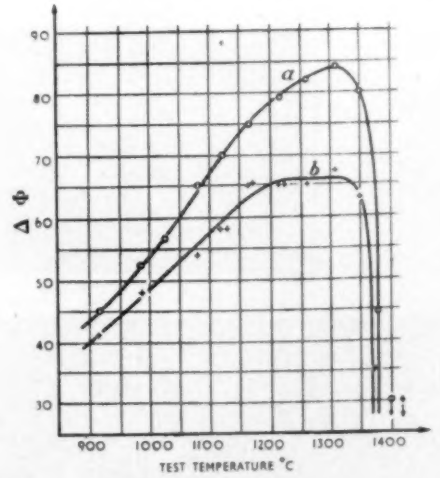
19 *Influence of structure. Cr-Ni austenitic stainless. By joining the points relating to the same one cast, the evolution of the ferrite content with temperature for each of the compositions studied can be seen*

Hot tensile tests. ½-in. square forged bar. Preliminary treatment: air quenched 1,050°C./1 h. Each curve corresponds to one test temperature
Speed of deformation 500%/sec.



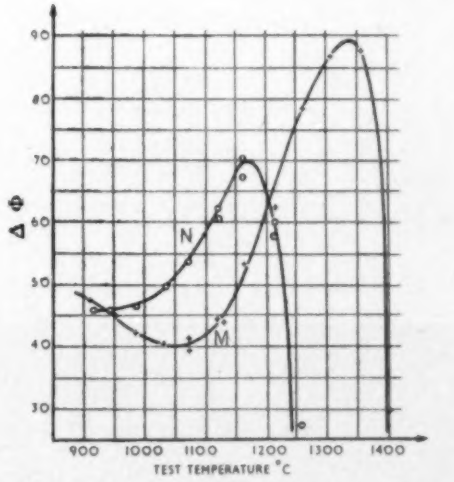
20 *Influence of structure. Steel K, 12% Cr*

Hot tensile tests. ½-in. forged square bar. Preliminary treatment: 900°C./30 ft. furnace
Speed of deformation 500%/sec.



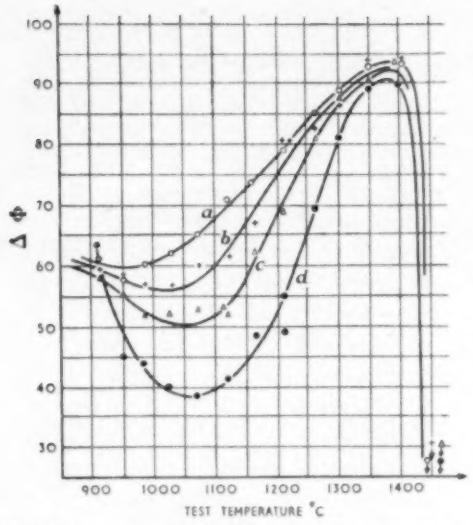
21 *Influence of lead. 18/8 austenitic*

Hot tensile tests. Steel L. 30-kg. (66-lb.) ingots forged into ½ in. square. (*a*) 0·001% Pb. (*b*) 0·042% Pb. Lead added to second 30-kg. ingot at moment of pouring. Preliminary treatment: air quenched 1,050°C./1 h.
Speed of deformation 500%/sec.



22 *Influence of boron. Steels M and N, 18/8 austenitic*

Hot tensile tests. 10-kg. (22-lb.) ingots forged into ½ in. square. Treatment: air quenched 1,050°C./1 h. M is ordinary 18/8 steel. N is similar steel with 0·050% B added
Speed of deformation 500%/sec.

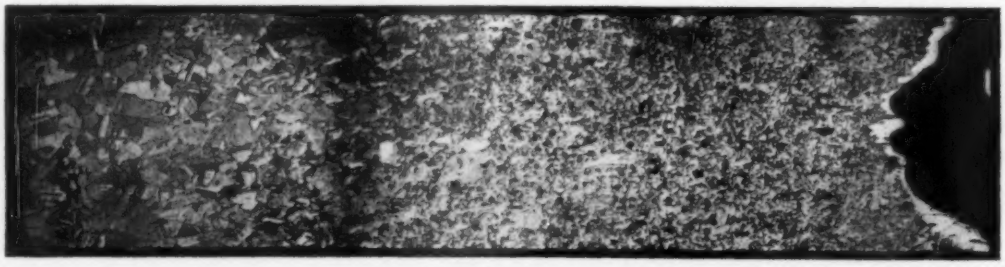


23 *Influence of aluminium. Steel O, 5% Cr, 0·5% Mo. Mild*
30 kg. (66-lb.) ingots forged into ¾ in. square. Preliminary treatment: 900°C./30 ft. furnace
Speed of deformation 500%/sec.

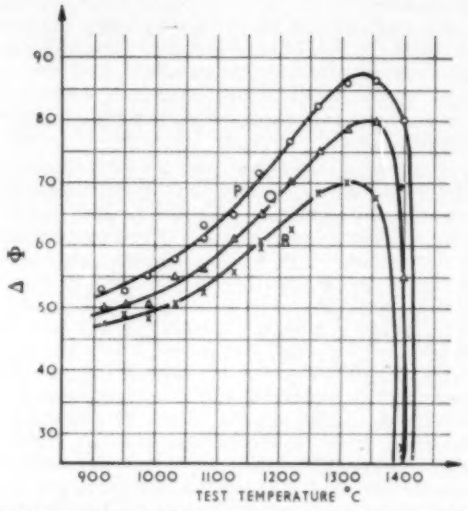
aluminium have been added in a series of 66-lb. ingots from the same cast. The influence of this element on this phenomenon had already been pointed out by Dauvergne, Pélabon and Ivernel.[9] It may be considered with these authorities that it is connected with the precipitation of aluminium nitrides previously dissolved. This precipitation would occur during the process of deformation itself and the mechanism of this phenomenon would be similar to that of the detailed study with austenitic steels.[10]

Phenomena of recrystallization The authors have observed that, in a large number of practical instances, hot ductility at high temperatures is all the greater as the speed of deformation is lower. It is possible that this phenomenon can be explained by a very rapid recrystallization of the steel taking place during deformation of the metal itself. The favourable effect of this recrystallization would be all the more noticeable in proportion as the length of time during which it occurred was longer, that is to say, as the speed of deformation was lower.

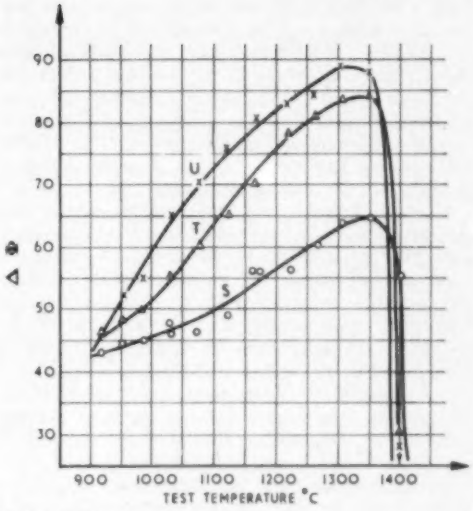
This hypothesis particularly allows the taking into account of the improvement in ductility observed at high temperature when working is done in a series of passes (fig. 13). The time during which the steel is able to recrystallize during working is much longer in the method of non-continuous deformation. Recrystallization can, indeed, be taking place during the intervals between the various working passes. By the same token it can equally be conceived that the improvement due to a process of non-continuous working may be more marked when the steel is deformed at high speed. In this case, indeed, recrystallization has only been able to take place to a very incomplete extent during the actual working of the metal.



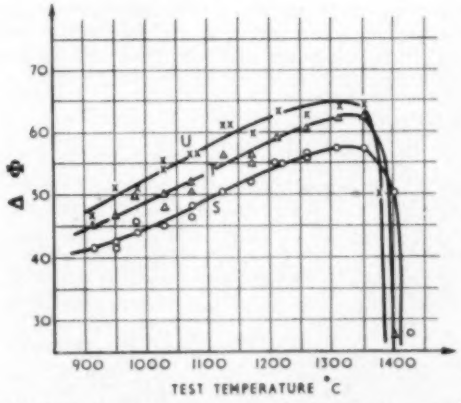
24 *Influence of original grain size on recrystallization during deformation of test-pieces of G steel broken at* 1,150°C.
(*a*) BELOW The recrystallized zone, with a fairly small grain, stretches for about ¼ in. from the broken end of the hot tensile test-piece (about 4¼ in. on the micrograph, 35 mag.)
(*b*) RIGHT For the same steel, but with the grain coarsened by a prior heat treatment, the recrystallized zone, with a relatively very fine grain, is hardly more than 0·001 in. thick from the broken fracture of the hot tensile test-piece



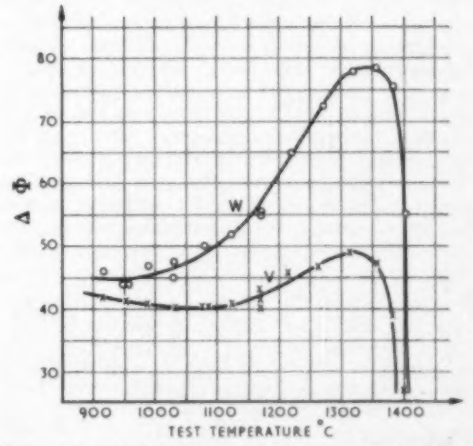
25 *Influence of molybdenum. Steels P, Q, R, 18/8 austenitic*
Hot tensile tests. 10-kg. ingots forged into ½ in. square. Preliminary treatment: air tempered 1,050°C./1 h.
Speed of deformation 500%/sec.



26 (*As* **25**, *but with titanium*)



27 (*As* **26**, *but with greater speed of deformation, namely,* 40,000%/*sec.*)



28 *Influence of cerium addition. Steels V and W, 18/8 Mo*
Hot tensile tests. 30-kg. ingots forged into ½ in. square. V steel 18/8 with Mo. W is similar steel with final addition of 0·3% Ce. Preliminary treatment: air tempered 1,050°C./1 h.
Speed of deformation 500%/sec.

Micrographic examination of longitudinal sections of hot tensile test-pieces after fracture allows of this phenomenon of recrystallization being made evident. It can be seen that there is, in the neighbourhood of the fractured section, a recrystallized zone which stretches over a more or less extensive area of the deformed section. This phenomenon is shown in fig. 24. The size of the recrystallized zone increases with the temperature of working and can extend, at high temperatures, over the whole deformed length of the test-piece. For certain temperatures suitably chosen, the size of this zone can vary appreciably according to the nature or the treatment of the steel and these results generally agree quite well with the corresponding values of ductility. An example is given by

comparing figs. 24 (a) and 24 (b), which show that the recrystallized zone of a tensile test-piece broken at 1,150°C., of an 18/8 type of austenitic steel, is clearly larger when the metal shows a fine crystal structure (initial quenching at moderate temperature) than when it shows a large crystal structure (initial quenching at high temperature). In parallel with this we have seen that hot ductility is higher in the first case than in the second (fig. 14).

Certain elements can appreciably modify the ductility of steels at high temperature. For instance, with 18/8 stainless steels, the addition of elements such as molybdenum or tungsten greatly reduces the ductility of the metal at high temperature (fig. 25). On the contrary, the addition of deoxidizing elements such as titanium or cerium produces a reverse effect and leads to an improvement in ductility all the more pronounced as the temperature gets higher and the speed of working gets lower. This fact is shown in figs. 26 and 27 for titanium and in fig. 28 for cerium.

In accordance with the hypothesis formulated above, it can be said that everything happens as if these elements modified the speed of recrystallization of austenitic steels, some to reduce it (tungsten, molybdenum) and some to increase it (deoxidizing elements). In the latter case it is possible that the titanium or cerium have an effect on the speed of recrystallization either by their own influence or indirectly by acting as inhibitors of coarsening in the austenitic grain. The favourable influence of titanium on the hot working of 18/8 steels has already been pointed out by various authorities and Newell[24] was the first to attribute it to its deoxidizing action. The favourable effect of an addition of cerium on the hot working of stainless steels has also been pointed out on several occasions.[25, 26]

Choice of experimental conditions The above examples show that phenomena of precipitation and recrystallization can be produced in a hot steel during the process of deformation itself. The revelation of these phenomena depends largely on the experimental conditions adopted.

Conclusions

This investigation has emphasized a very large number of factors which intervene to modify the hot ductility of steels. This is principally dependent on conditions of working, on the structure and composition of the steel and on the method of production. The steelmaker and the metallurgist must, of necessity, collaborate with the forger or roller in finding the right solution of each problem.

It is only by systematic experimental investigations that it can be hoped to define the essential laws of ductility for each alloy steel. It has been shown that, for each type of working instrument, these rules can be different, since they depend principally on temperature, speed of deformation, method of deformation and type of stress imposed on the metal. It has also been shown that they may also depend to a large extent on the total heating cycle applied to the metal: preliminary heating on the one hand and cooling during working operations on the other.

It has been shown that there can be produced in the metal, during the process of working itself, harmful precipitation phenomena and helpful recrystallization phenomena. These phenomena are produced with certain kinetics and their influence on the ductility of the metal is consequently so much the more marked as the speed of deformation is slower. An analogy can here be established with the phenomena, which are produced during the quench cooling of a treated steel, during which the cooling kinetic is superimposed on the transformation kinetics. Only the study of the austenite isothermic transformations has enabled the interpretation of the laws of heat treatment by dissociating these two kinetics. In parallel it has been shown here that the laws of the hot ductility of steels could be analysed more fully by comparing the results obtained with very different speeds of working, which indirectly comes to the same process as dissociating the kinetics of precipitation or recrystallization from the kinetic of deformation. It is only if all the factors enumerated above are taken into account, by an extensive preliminary study of each particular case, that forgeability tests could be valuable aids as much to the steelmaker as to the management of the hot-working shops.

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Application of electron microscopy

Structure of pearlite formed during the continuous breakdown of austenite

IVAN HRIVŇÁK

An electron microscope study of the morphology of the internal structure of lamellar pearlite in various steels continuously cooled from the austenitization temperature was reported in Hutnické Listy, 1959, (2). *The present English version is the seventh of a series illustrating the role of the electron microscope in various metallurgical investigations*

MUCH SPACE in metallurgical journals has been devoted in recent years to the study of the mechanism of the transformation of pearlite. This is because the transformation of pearlite is one of the basic problems of the physics of metals, and has unlimited application in the heat treatment of steels.

The problem of the mechanism of the transformation of pearlite has been the subject of extensive works by Mehl,[10, 12] Mehl and Hagel,[1] Hultgren,[4] Gardin,[15] Modin[11, 16] and others, which outline in a realistic manner the basic problems of the nucleation and growth of pearlite, of the interlamellar spacings, of the morphology and of other physical properties. An excellent review and criticism of the literature sources has recently been provided by Cadek.[9]

This work falls outside the framework of the current methods of studying eutectoid reactions in steels, since it is devoted only to morphological problems of pearlite formed not during the isothermal, but during the continuous breakdown of austenite.

The study of the continuous breakdown of austenite has been clearly contrasted with the isothermal reactions by Grange and Kiefer[5] amongst others. Whereas during the isothermal breakdown the resultant structure is uniform, the structures resulting from the continuous breakdown are a mixture, or a series, of structures, out of which each corresponds to a definite transformation temperature. We could, in fact, assert that the continuous breakdown may approximate to an endless series of infinitesimal isothermal transformations following one after another. But in reality the transformations mentioned are not infinitesimal, since they cover the sufficiently wide range of temperatures necessary for the destruction of the relationships governing the thermo-dynamic equilibrium transformation. The kinetics of the continual breakdown of austenite in the pearlitic zone are therefore remarkably complex, and their clarification demands further systematic study.

For the study of the morphology of lamellar pearlite nine groups of steels were used with increasing carbon contents, in some instances alloyed with chromium and molybdenum. All the steels received normalizing heat treatment, and then after austenitization were cooled in air under atmospheric conditions.

For observation with the electron microscope carbon extraction replicas, and in some instances negative collodion replicas, shadowed with chromium,[17] were used. All the surfaces were electrolytically polished in a solution of the type $HClO_4 + CH_3COOH + H_2O$, and etched with 2% HNO_3. In some instances use was made of carbon extraction replicas shadowed with chromium. Onto the polished, etched and cleaned surface a thin layer of chromium was vaporized at a moderate angle, and a layer of carbon at right angles. The film of chromium and carbon was then separated from the surface in 15% HCl. The advantage of this method of analysis is the ease of interpretation of the photographs obtained, while preserving a power of resolution exceeding 50 Å.

By means of carbon extraction prints it is possible to record the morphology of the primarily disintegrated carbides of pearlitic cementite; this subject, however, cannot easily be observed, because the cementite lamellae are normally oriented in the

same direction as the surface of the polished specimen. But, in fact, this method was applied to tertiary cementite, and the results obtained are described in the following text. What remains on a carbon film after the separation of the individual carbide particles, or the pattern of their imprint, depends on the method and degree of etching and also on the three-dimensional size of the particles under observation.

Steels with 0·10—0·15% carbon

In low-carbon unalloyed steels apart from pearlitic cementite there may be a high degree of precipitation of non-lamellar, tertiary cementite. The morphology of tertiary cementite was discovered in three types of steel with a carbon content of 0·10 to 0·15%. The proportion of tertiary cementite to pearlitic cementite was found to reach a high level. The structure of non-lamellar cementite precipitated on the boundaries of the ferritic grains is typified for instance by fig. 1, with partial islands of ferrite and a pronounced boundary between the two parts of the cementite.

Modin[16] made a detailed study of the morphology of isolated carbides of pearlitic and bainitic cementite and found that, whereas pearlitic cementite is two-dimensional, bainitic cementite has a three dimensional orientation in a peculiar form. From isolated carbides of tertiary cementite it may be judged that they likewise have a spatial state with a sufficiently complicated orientation. A typical example of such a carbide isolated on a carbon extraction replica is shown in fig. 2. From the micro-photograph is partly visible a cross-section of the carbide on the surface of the polished specimen, and also the orientation of the remaining part of the carbide to that surface. And since in this section it is not a matter of a regular structure, it is evident from the orientations of its particles that it is morphologically sufficiently defined.

In a further part of the work an examination was made of the ratio of tertiary cementite to pearlitic cementite. It has already been shown in a previous paper[18] that tertiary cementite is a development from pearlitic cementite. In the study presented this discovery was also confirmed in other types of steels. Fig. 3 shows the orientation of a pearlitic island in low-carbon steel. From this figure may be seen the almost regular structure of the cementite lamellae, and between them a panel of ferrite with varying interlamellar spacings. The tertiary cementite which was formed by carbon diffusion from the surrounding ferritic grains, links its structure directly onto the pearlitic cementite. The indistinct boundary between the tertiary cementite and the proeutectoid ferrite is caused firstly by the unfavourable orientation from the point of view of the direction of the carbon vaporization, secondly by the actual method of producing the replica and finally by the diffusion processes which dominate the formation of cementite.

Steels with 0·43% carbon (CSN 11,600)

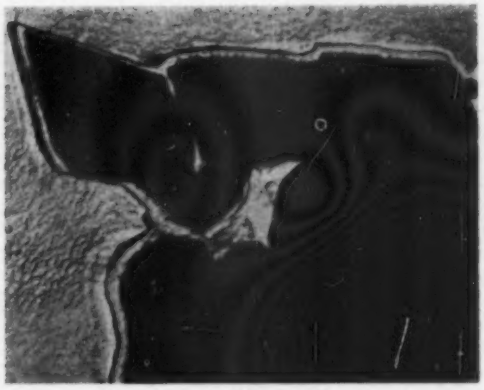
With an increase in the carbon content there is a reduction in the quantity of proeutectoid ferrite, while the pearlite which is formed by the continuous breakdown of austenite is less degenerate. Apart from the ratio between the pearlitic and proeutectoid ferrite, the morphology of the structure of the cementite lamellae, their after - inhomogeneity etching and their disorientation were observed. Puttick[13] has recently drawn attention to the inhomogeneity of pearlitic cementite which he discovered after electrolytic etching in 10% H_2CrO_4; he attributes this to one of two types of segregation in the interior of the carbide. Either it is variation in the carbon content in the various parts of the carbide in relation to Fe_3C, or in the case of alloy steels it is inhomogeneity in the content of an alloying element. Thus, for instance, manganese and nickel, where they are present in steel in a sufficient quantity, can be dissolved in cementite to a considerable extent.

Fig. 4 is typical of inhomogeneity in the diffusion of cementite after etching with nital. It is interesting that as distinct from Puttick this uneven disintegration is sufficiently ordered, and from detailed observation it may be found that the lamellae run in two directions running at right angles to each other.

Fig. 5 shows the boundary between pearlite and proeutectoid ferrite. Modin[11, 16] showed that in certain instances proeutectoid ferrite may be a development from pearlitic ferrite. A similar instance is characterised in this figure also, where there is no boundary between the two types of ferrite.

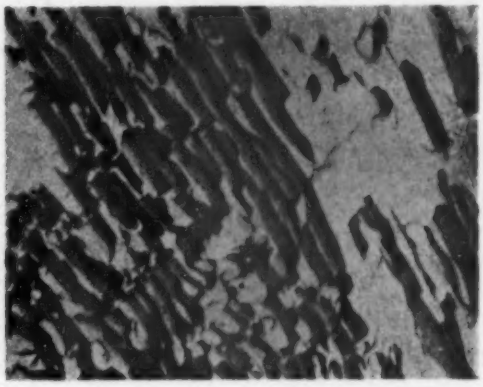
A pearlitic column is defined as a zone of the pearlitic grain which has mutually parallel lamellae. During the continuous breakdown of austenite thermo-dynamic equilibrium conditions are not preserved in the whole of the grain, and the pearlite which forms is different from the ideal structure. Amongst its visible defects are discontinuity in the structure of the cementite lamellae, dual crystallization and the like, which may all be termed collectively as growth faults. One of these faults is also shown in fig. 6, namely, crystallization oriented from two directions, which has probably been caused by the meeting (collision) of two growing grains. A similar morphology of pearlite in this steel is also shown in fig. 7, in which the boundary between the two areas of ferrite is clearly marked. As the orientation of the lamellae with reference to the direction of application of the carbon is

1 *Tertiary cementite. Collodion* × 9,500

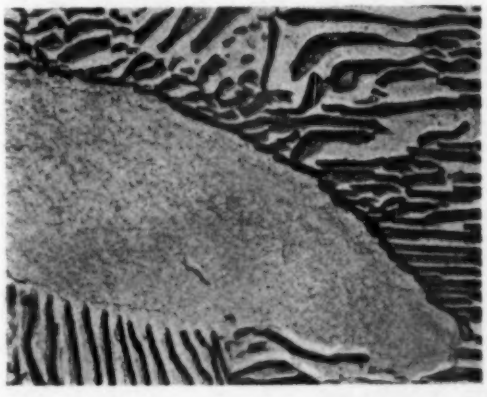


2 *Isolated cementite particle. Carbon extraction replica* × 9,000

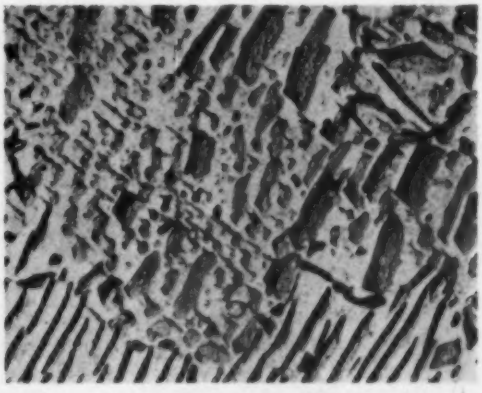
3 *Pearlitic island. Carbon extraction replica, shadowed with chromium* × 9,000



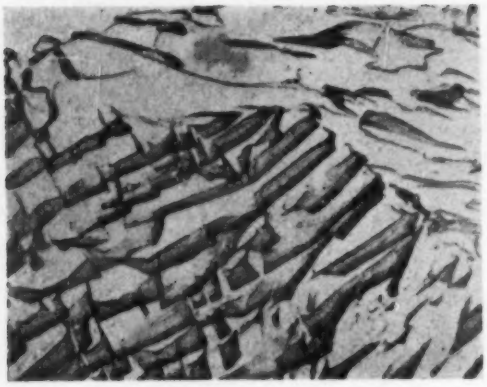
4 *Inhomogeneity of cementite. Carbon extraction replica* × 9,000



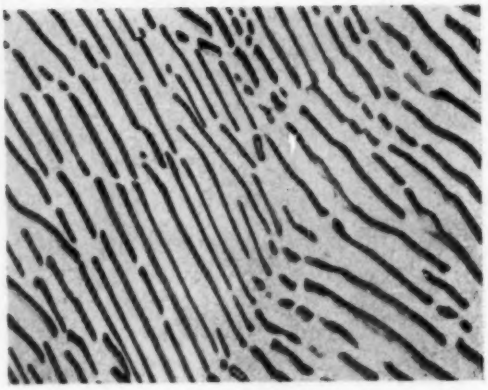
5 *Prozutectoid ferrite and pearlite* × 9,000



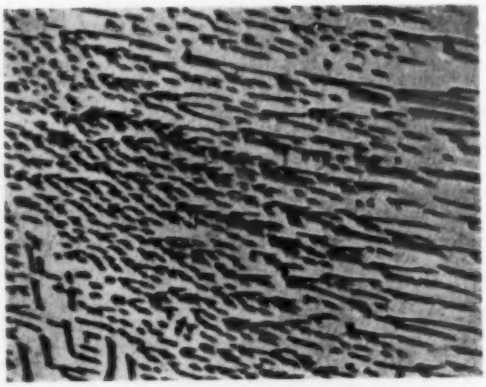
6 *Faults in the growth of pearlite* × 9,000



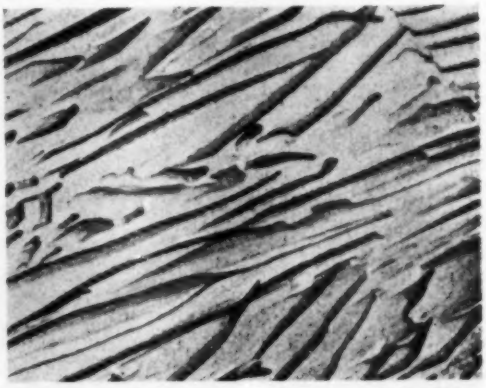
7 *Outline of cementite in pearlite* × 9,000



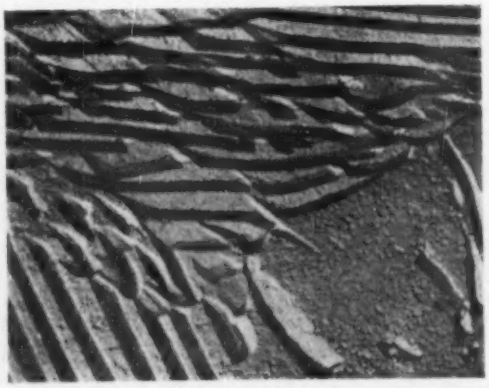
8 *Typical morphology of pearlite* × 8,000



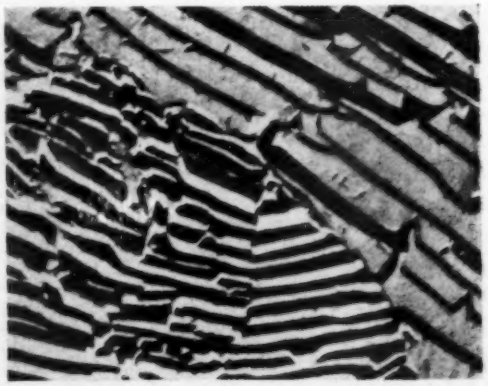
9 *Two directions of the growth of pearlite* × 9,000



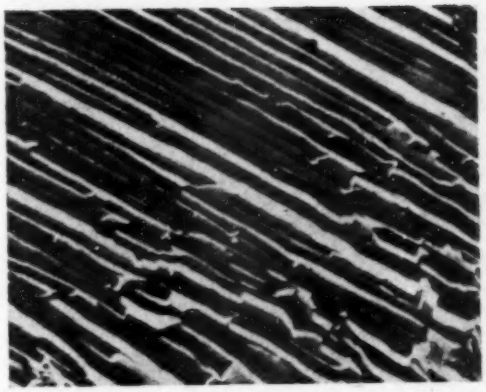
10 *Lamellar pearlite* × 9,000



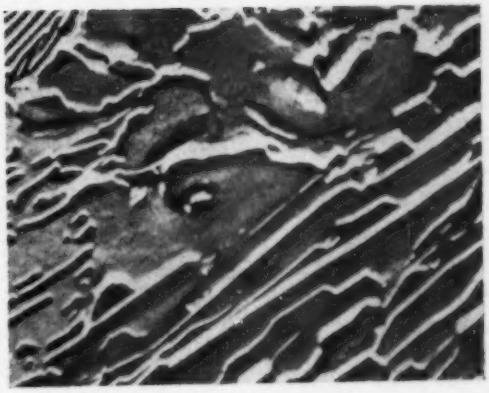
11 *Proeutectoid and pearlitic ferrite* × 9,000



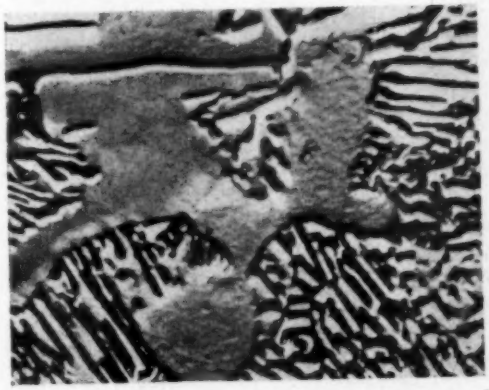
12 *A pearlitic grain* × 10,000



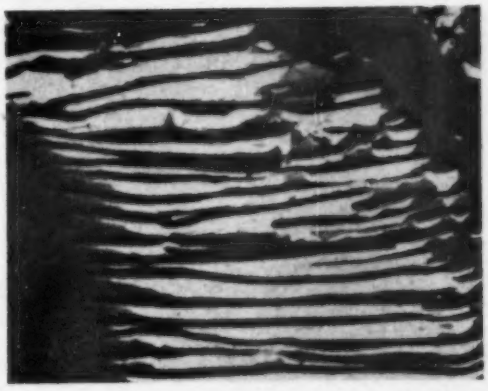
13 *Structure of a pearlitic column* × 9,000



14 *Pearlite* × 9,000



15 *Degenerate pearlite* × 9,000

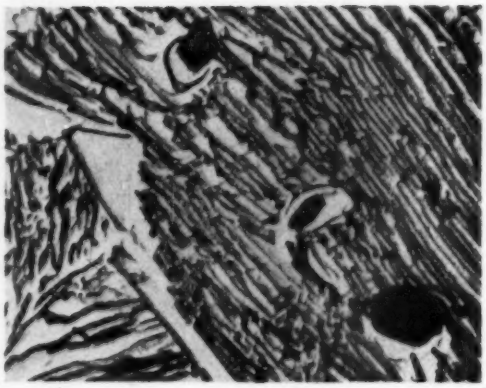


16 *The orientation of pearlitic and proeutectoid ferrite* × 9,000

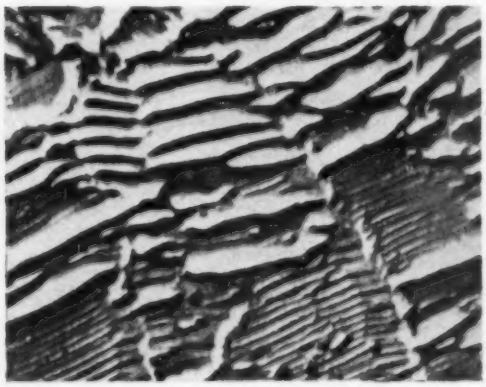
17 *Change in the interlamellar spacing* × 9,000

18 *Pearlite and secondary cementite* × 9,000

19 *Pearlite* × 9,000

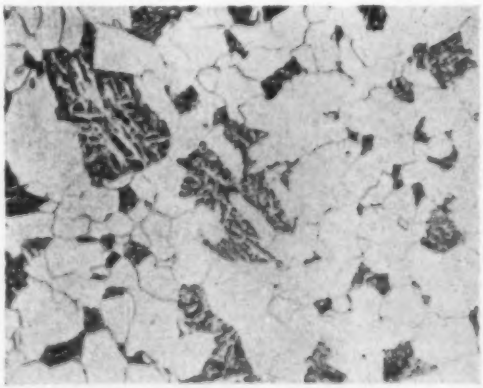


20 *Fine pearlite and carbides* × 9,000



21 *Dual crystallization of pearlite* × 9,000

22 *Dual structure of pearlite* × 9,000



23 *Molybdenum pearlite under an optical microscope* × 200

24 *Details of the internal structure of molybdenum pearlite under an electron microscope. Collodion* × 9,000

unfavourable, the shape of the cementite is not normal.

Steels with 0·6 to 0·65% carbon

In this class two groups of steels with a lower and a higher carbon content were observed. Fig. 8 is typical of the morphology of pearlite with which we have become familiar through the optical microscope. On the other hand fig. 9 shows an interesting example of the breakdown of the cementite lamellae which is in distinct contrast to pearlitic ferrite. Once again it is a matter of conflict between two directions of growth which intersect each other. Where the cross-section is unfavourable, a simple structure of pearlite may not be readily observed and interpretation is difficult (fig. 10). A conflict between two directions of growth is again shown in fig. 11, where once more the relationship between pearlitic and proeutectoid ferrite can be seen.

The second group of steel had a higher carbon content (0·65%). Fig. 12 shows an interesting conflict between two pearlitic columns. Fig. 13 shows the detail of the structure of a column with inhomogeneities in the cementite lamellae. The orientation of the proeutectoid ferrite relative to the pearlitic ferrite is demonstrated by the following micro-photographs, figs. 14, 15 and 16. And although in figs. 15 and 16 it is partly a matter of degenerate pearlite, at the same time the pearlitic and proeutectoid ferrite are linked. Fig. 17 is typical of a frequent instance of a morphology of pearlite forming during continuous and even cooling; the pearlite which formed in the range of higher temperatures also has greater interlamellar spacings; at the lower formation temperature, on the other hand, there are correspondingly smaller spacings. At a definite temperature which corresponds to the breakdown of the thermodynamic equilibrium, pearlite is initiated by new cementite nuclei which lead to a reduction in the interlamellar spacings. Such an instance is typified by fig. 17, from which it may be seen that new and finer cementite lamellae are linked with the original lamellae.

Steels with 1·19% C and 1·22% Cr

Figs. 18 and 19 are typical of the orientation of very fine pearlite and of its impact with a hypereutectoid carbide alloyed with chromium. Fig. 20 is typical of the inhomogeneity of the structure of the cementite lamellae. A typical example of dual crystallization of pearlite is given in fig. 21. Fig. 22 is also morphologically very interesting; it presents stepwise precipitation of the cementite lamellae, while within the individual coarse steps further lamellae are precipitated. The interpretation of these morphological peculiarities is extremely difficult, and many new and systematic experiments will be required for their explanation.

Morphology of rare 'molybdenum' pearlite

The morphology of pearlite alloyed with molybdenum was examined in Lof special steel (0·15% C, 0·55% Mn, 0·20% Si, 0·45% Cr and 0·55% Mo). A typical structure of such pearlite at low magnifications is shown in fig. 23, and at high magnifications as revealed by an electron microscope in fig. 24. The cementite lamellae have a peculiar, almost flake-like appearance with a very irregular outline. In fig. 24 there are remarkable lamellar formations of a very fine component forming inside some of the carbide particles. Where such degenerate pearlite occurs, it is difficult to talk of any interlamellar spacing or even of any regular structure of any kind at all.

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NEW FILMS

'Cutanit Cemented Carbides'

THE DEVELOPMENT of cemented carbides as a cutting medium has revolutionized machine shop practice over the last 30 years and is enabling engineers to achieve greater outputs with reduced machining costs.

The film 'Cutanit Cemented Carbides' sets out to emphasize the tremendous care and technical knowledge which goes into the production of 'Cutanit' and demonstrates the exceptional qualities of this material in many varied machining applications.

Commencing with the fine tungstic oxide powder, the many manufacturing processes are followed through to the finished hard-metal sintered tips. The film goes on to show the modern techniques used in the manufacture of cutting tools and also stresses the importance of correct carbide grade selection for particular machining applications. Then follows a series of sequences showing 'Cutanit' in use in copy lathe turning, heavy-duty milling, planing (notably the surface milling and planing of die blocks), trepanning, reaming, press tools, steel strip splitting.

Finally, its outstanding performance as a mould lining in the manufacture of refractory bricks is shown.

The production of 'Cutanit' tools is undertaken co-operatively by Metro-Cutanit Ltd. and Jessop-Saville Ltd.

Beryllium copper

Part 2 Heat treatment

G. FITZGERALD-LEE, F.R.Econ.S., M.I.E.I., A.R.Ae.S.

Beryllium copper with its combination of good mechanical properties, electrical and thermal conductivity, and resistance to corrosion is a most useful alloy in such applications as springs and electrical contacts. The following article is concluded this month with a consideration of heat treatment procedures

Beryllium-copper alloys are typically precipitation hardening; they can be softened by quenching from a high temperature and afterwards hardened by heating to a moderate temperature.

In fig. 1, showing part of the equilibrium diagram of the beryllium-copper system, four solid phases appear, marked respectively a (alpha), b (beta), g (gamma) and d (delta). The diagram indicates their distribution in respect of the two variables, composition and temperature, after sufficient time has been allowed at any particular temperature for the attainment of equilibrium. In the upper part of the diagram a fifth phase, liquid, appears, and it will be seen that the temperatures at which the material starts to melt and becomes completely molten vary considerably with composition.

In the attainment of equilibrium, time is an important factor: the higher the temperature the more rapidly is equilibrium achieved. Thus, if an alloy is maintained at a particular temperature until equilibrium is reached, and is then cooled sufficiently rapidly—as by quenching—it is generally possible to suppress the changes which would occur at lower temperatures during slow cooling, and so to retain the structure and properties appropriate to the quenching temperature.

Equilibrium principles

Applying these principles to beryllium copper, it is evident from the diagram that if an alloy containing less than 2·7% of beryllium is brought into equilibrium at, and quenched from, any temperature to the left of the boundary ABLOP, it will consist of the α phase alone. The crystal lattice is then similar to that of copper itself and the metal will consequently remain, like copper, relatively soft and ductile.

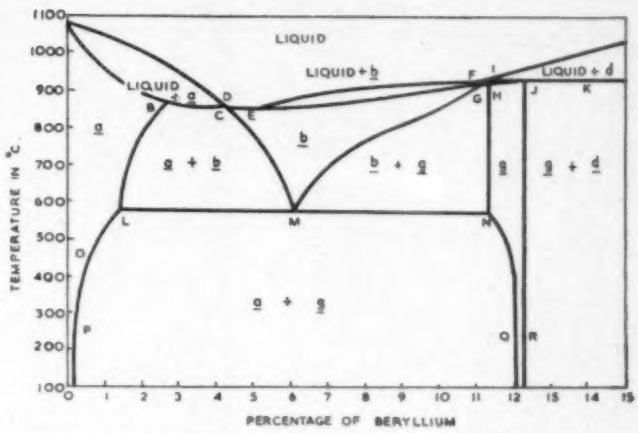
The temperature range within which this result can be achieved depends on the beryllium content; for the usual 2% beryllium alloy it is comparatively narrow, lying between about 780°C. on the boundary BL and about 890°C. on AB, where incipient melting takes place. The practical solution heat-treatment temperature for normal beryllium copper is kept well within this range and is usually about 800°C.

It is apparent from the diagram that the alloy so quenched is unstable at lower temperatures and would revert to the $\alpha + \gamma$ structure should favourable conditions arise. At room temperature, the reaction—if it occurs at all—is so sluggish that the quenched condition can be retained almost indefinitely, but it becomes increasingly rapid as the temperature is raised. Moreover, increase of temperature favours diffusion, and consequent agglomeration of the precipitated γ into particles of larger size.

After moderate times at the normal hardening temperature of from 300°C. to 350°C. the particles of precipitated γ are exceedingly minute and are well distributed throughout the α matrix. The regularity of the α crystal lattice is consequently disturbed and it becomes difficult to push layers of atoms over one another by externally applied forces. The result is a great increase in the mechanical strength and hardness of the alloy.

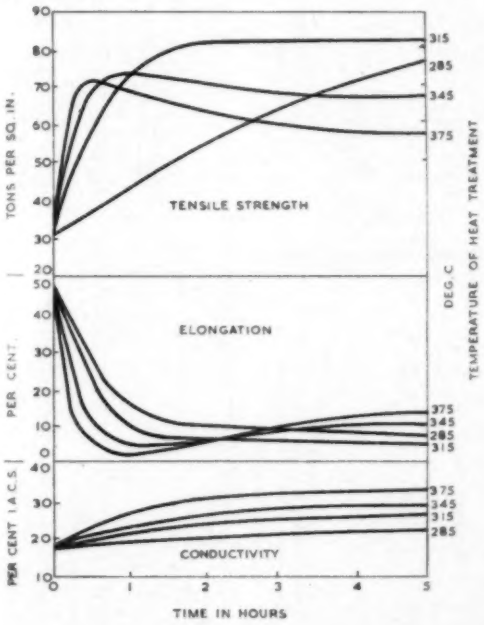
At somewhat higher temperatures and longer times, however, the submicroscopic particles of γ can coalesce to form larger entities, leaving the α crystals in much the same condition as before precipitation occurred. Thus the strength and hardness tend to fall and the material is said to be 'over-aged.' As will be seen later, a controlled degree of over-ageing is often exploited in practice in order to obtain special combinations of properties.

To obtain the greatest degree of hardening it is



1 RIGHT *Equilibrium diagram of the copper-beryllium system (copper-rich alloys)*

2 BELOW *Effect of precipitation heat treatment on solution-annealed beryllium copper (Beryllium Corporation)*



important that both stages in the heat treatment should be correctly controlled. If the solution temperature is not above the boundary BL in the diagram, or if the quenching is not rapid enough, some of the beryllium may be ejected prematurely as β, and less will be available to harden the alloy during subsequent precipitation. On the other hand, if the solution temperature is too close to the solidus AB in the diagram, objectionable grain-growth, or even incipient melting, may take place.

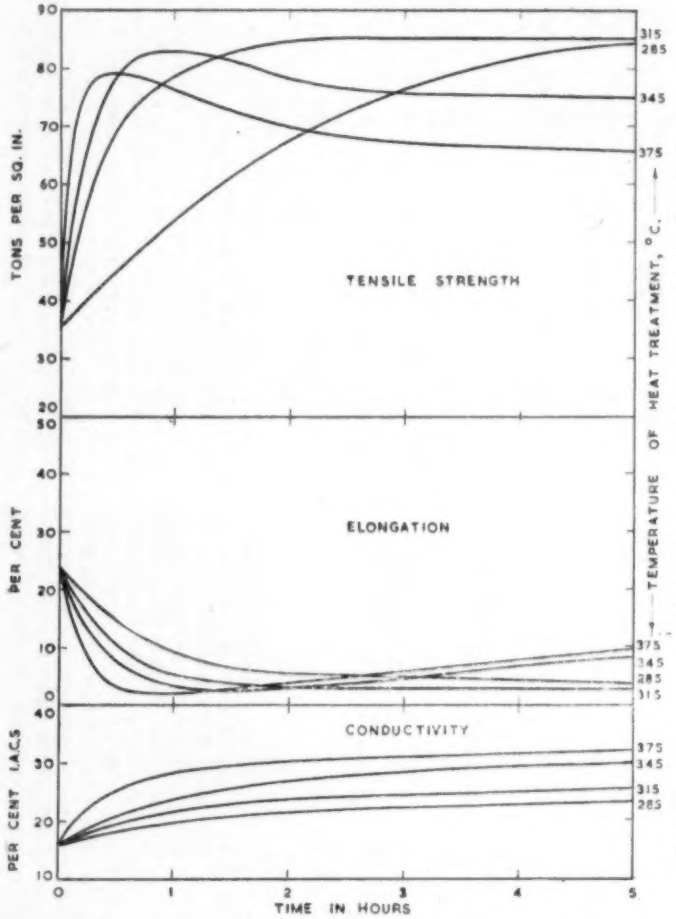
These boundaries, especially BL, are quite steep, and small variations of beryllium content, as well as the presence of added elements like cobalt and nickel, make a considerable difference to the optimum solution temperature. In the second stage of heat treatment, the times and temperatures which give maximum hardness and strength do not as a rule lead to maximum conductivity and freedom from elastic drift, and a compromise is often required in controlling the process.

Commercial alloys usually contain other elements—either as intentional additions or as impurities—and the analytical figure for beryllium may not therefore accurately represent the effective beryllium content, because the element is easily oxidized and, unless due care is exercised in the melting and casting processes, some may be present as entrapped oxide which plays no part in the heat treatment. For such reasons, the equilibrium diagram should be regarded as no more than a useful guide to the probable behaviour of the metal, and as an indication of the nature of the changes which can be brought about by heat treatment. Although a valuable yardstick, it cannot be expected to apply with quantitative precision in all cases.

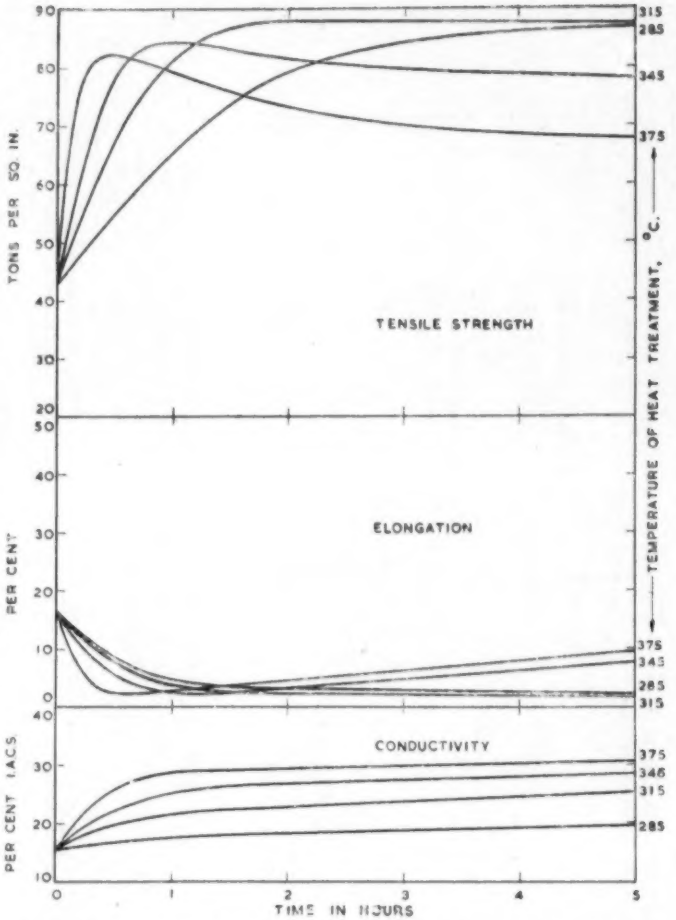
It is important to distinguish between the hardening effect of precipitation heat treatment and that brought about by cold work. Material supplied in the commercial tempers called quarter hard, half hard and hard has merely been cold worked to progressively greater degrees after solution heat treatment and will respond to subsequent precipitation hardening. The effect of precipitation hardening can, in fact, be superimposed upon that of cold work to give exceptionally high strength.

Solution annealing

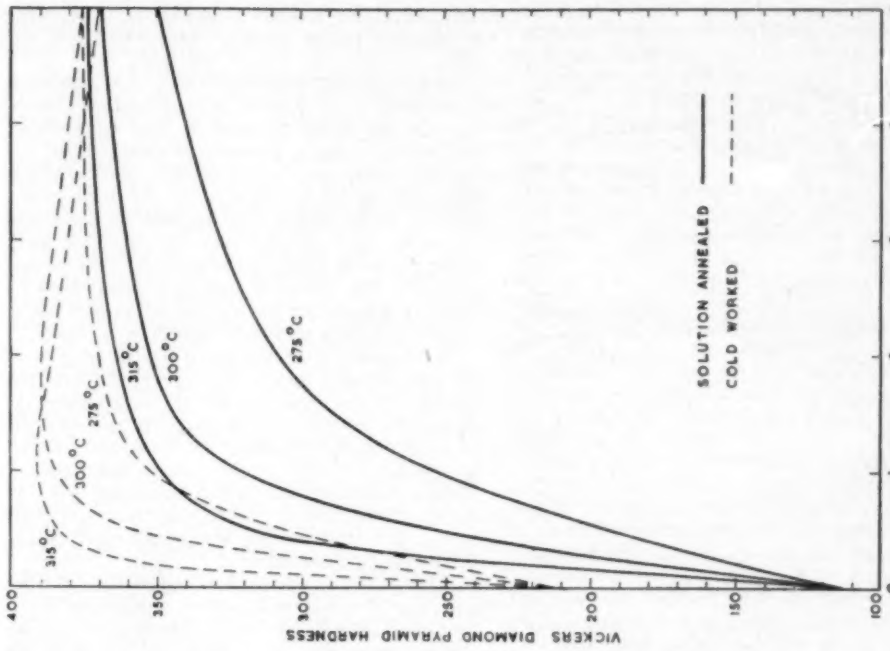
The object of solution heat treatment is therefore to form a single phase α solid solution which is



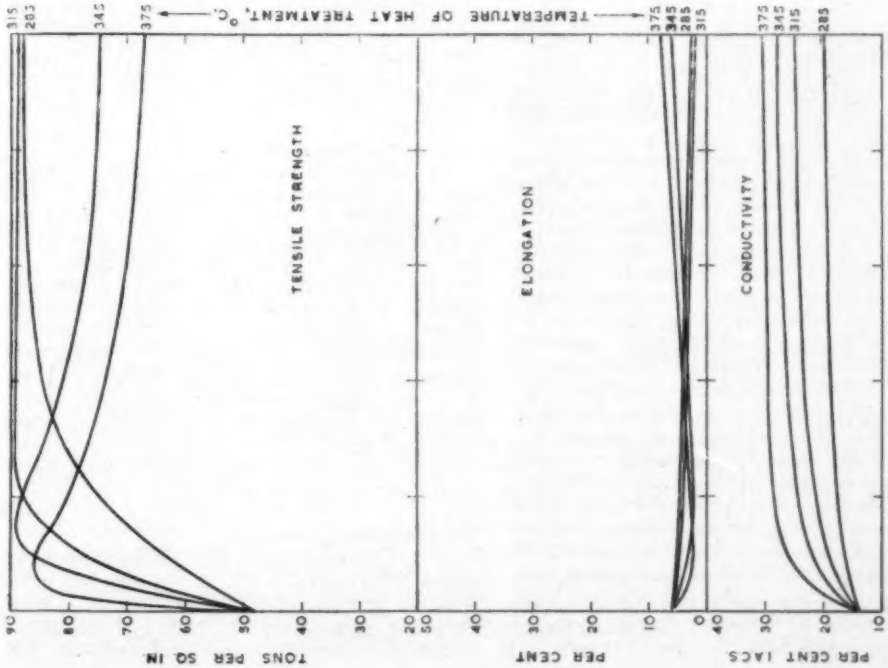
3 *Effect of precipitation heat treatment on quarter-hard beryllium copper (Beryllium Corporation)*



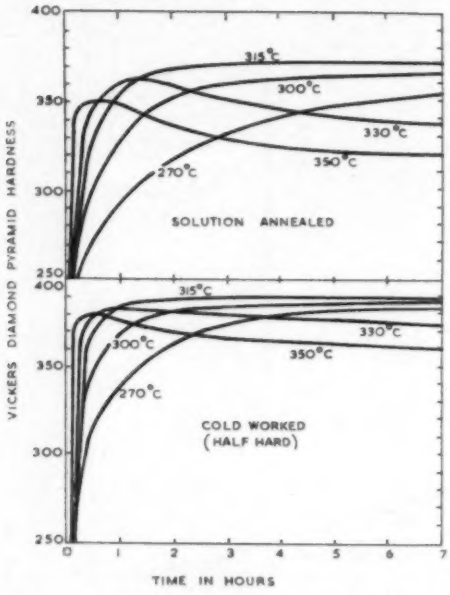
4 *Effect of precipitation heat treatmcnt on half-hard beryllium copper (Beryllium Corporation)*



6 *Effect of precipitation heat treatment on the hardness of beryllium copper (Johnson, Matthey & Co. Ltd.)*



5 *Effect of precipitation heat treatment on hard-worked beryllium copper (Beryllium Corporation)*



7 *Effect of precipitation heat treatment on the hardness of beryllium copper (Beryllium and Copper Alloys Ltd.)*

comparatively soft and ductile. It is sometimes called 'homogenizing,' while the term 'solution annealing' is appropriate when the process is applied to material which has previously been hardened by cold work.

Reference to the diagram shows that the temperature required for the purpose is relatively high and that its range becomes progressively narrower as the beryllium content of the alloy is increased. At such temperatures there is a tendency to cause grain growth if the time of exposure is unduly prolonged, while the access of oxygen may lead to embrittlement of the surface layers or even of the whole section in the case of thin stock. It follows that considerable care is necessary in the practical control of the process.

For normal beryllium copper containing about 2% beryllium, the temperature of solution heat treatment ranges from about 790°C. to 820°C. Control can, however, be facilitated by reducing the beryllium content to about 1·7%, in which case the lower limit for the temperature of solution heat treatment is brought down to about 760°C. with correspondingly less tendency to grain growth.

The solution heat treatment temperature for low beryllium copper is, however, somewhat higher, ranging from about 850°C. to 920°C. This is less paradoxical than it might at first appear to be, being attributable to the greater cobalt content of the alloy.

In all cases the time of heat treatment should be kept rather brief, in order to restrict grain growth, but must be sufficient to ensure that the whole of the furnace reaches the desired temperature. It will depend to some extent on the thickness of the stock and on its arrangement in the furnace, but from 10 to 30 minutes may be taken as a practical guide for light material such as strip and wire, extending up to several hours for bulky castings and forgings. The heat treatment must always be completed by a rapid and efficient quench in cold water; 'slack' quenching should be rigorously avoided.

Although the type of furnace for the purpose is not particularly important—provided that the control of the temperature is adequate—it is highly desirable—if not essential—to use an inert or slightly reducing atmosphere, free from sulphur compounds which would cause discoloration. Electric furnaces with atmospheres consisting of the dried products of cracked and burnt ammonia are suitable, but neither steam atmospheres nor salt baths are recommended.

Oxide, charred lubricant or other abrasive films may lead to serious tool wear in subsequent fabricating operations, and for this reason, as well as for surface appearance, it is important to clean the stock thoroughly before solution heat treatment or annealing. If it is impracticable to use an inert atmosphere, the time of heat treatment should be kept to a minimum, and the oxide film which will inevitably form should be removed by pickling.

Sub-critical annealing

An essentially different type of heat treatment, known as sub-critical annealing, is also in use. Heating for 8 hours at about 550°C. causes the α phase to recrystallize with little grain growth. At the same time a considerable proportion of the beryllium is precipitated as γ, which spheroidizes. Material in this condition has good cold-working properties and can be hardened by drawing or rolling, although its response to precipitation hardening is negligible. In the work-hardened state it can be formed directly into springs and similar articles and requires no subsequent heat treatment other than stress relief at 150°C. for from 15 to 30 minutes. Tensile strengths ranging from 60 to 75 tons/sq. in. can be achieved.

Precipitation hardening

In the practice of precipitation hardening careful control is necessary if the best results are to be obtained, and the process can be modified to meet particular requirements in respect of mechanical and physical properties in the finished product. For

example, conditions which lead to maximum hardness and strength differ from those which afford maximum conductivity or freedom from elastic drift. Moreover, not only the exact composition of the material but also the degree of cold work to which it has been subjected affects the response to precipitation hardening. In general, however, normal beryllium copper needs from 2 hours at 310°C. to ½-hour at 350°C., while for low-beryllium copper, with similar periods of time, the temperatures range from 420°C. to 470°C.

Even within these ranges there is considerable scope for variation and, in the absence of adequate instructions from the supplier, it is desirable to carry out a few pilot trials on any new consignment of beryllium copper before starting full-scale production. Nevertheless figs. 2 to 7 give a guide to the results which may be expected in the case of normal beryllium copper, although individual proprietary alloys may behave somewhat differently from one another. This can be seen by comparing figs. 6 and 7, which show the effects of heat treatment on the Diamond Pyramid Hardness of normal beryllium copper from two different sources.

In general, all the diagrams show the same features. At temperatures less than 300°C. response to heat treatment is relatively slow, and the full degree of precipitation hardening is not attained within an economical period of time. The optimum temperature is about 315°C. This gives full hardening in about 2 hours for the solution-annealed or lightly cold-worked material, or in about one hour for the harder grades. At higher temperatures there is a tendency for the alloys to over-age, particularly when they are in the cold-worked condition.

Effects of ageing

A moderate degree of ageing is not, as a rule, harmful, and figs. 2 to 5 show that it is accompanied by an appreciable improvement in conductivity as well as slightly increased elongation values. A further advantage of over-ageing is that it tends to improve the performance of calibrated springs by reducing drift of the zero setting in service and by slightly increasing the modulus of elasticity. This is due mainly to the more complete removal of internal stresses created in the metal by the cold forming processes. The elimination of internal stresses is, moreover, conducive to improved performance under fatigue conditions.

With such aims in view, some users advocate temperatures in the neighbourhood of 350°C. for from ¼ to 1 hour with solution-annealed material and from ¼ to ½ hour with the cold-worked grades. These short times are, however, difficult to control in practice because the heating-up period is an appreciable and variable proportion of the whole. Similar results can be obtained with greater reproducibility by adopting somewhat longer times at temperatures in the region of 330°C.

In deciding upon an appropriate heat treatment it must be remembered that the fabricating processes applied by the user himself will work-harden the alloy to a degree depending on their severity. For example, if solution-annealed material is subjected to severe deep drawing it must be regarded as half hard or even hard stock for purposes of heat treatment. Further, in the case of deep drawing, bending and similar processes, the degree of cold work is rarely uniform throughout the article, and some compromise in the time and temperature of heat treatment may become necessary to allow for this fact. It is clearly impossible to give recommendations covering all such contingencies, the best course being, as already mentioned, to carry out a few trials before proceeding to commercial production.

Reduction of the beryllium content to about 1·7% gives a form of normal beryllium copper which, although not quite so hard as the 2% alloy, tends to behave more consistently under precipitation heat treatment. This is due mainly to the fact—already referred to—that the conditions for solution heat treatment are distinctly less critical and consequently easier to reproduce under ordinary industrial conditions.

Heat treatment of low-beryllium copper

Procedure for the precipitation hardening of low-beryllium copper is basically similar to that for the normal alloy, but the temperature is higher and the conditions, on the whole, less critical, mainly because low-beryllium copper is rarely used for calibrated springs and other components calling for high precision and reproducibility of performance.

As in the case of the normal alloy, the optimum conditions for any particular product can best be found by trial. Low-beryllium copper shows a greater tendency to oxidize superficially during heat treatment than the normal alloy, not only because of the higher temperatures required but also because the alloy lacks sufficient beryllium to form the protective film of beryllia which is a feature of the normal alloy.

Furnaces and fixtures

Muffle furnaces, air-circulating furnaces or salt baths may be used for the precipitation heat treatment. They should preferably be equipped with thermostats, but in any case the control of temperature must be responsive and its measurement accurate. Muffles are comparatively inexpensive but tend to be slow in operation, and air-circulating furnaces represent an important im-

provement in this respect, combined with greater uniformity of temperature throughout the heated zone.

The temperature required for precipitation hardening is insufficiently high to cause serious oxidation, although protective atmospheres, mildly reducing in character and free from sulphur compounds which cause staining, can be used if desired to diminish the need for subsequent finishing. Also to minimize discoloration, it is important to remove all trace of dirt or lubricant before heat treatment. This is especially true in the case of lubricants containing sulphur compounds.

In the case of salt baths, care must be taken to wash the products thoroughly, for residual salt may lead to subsequent corrosion. Salt baths give quick heating with good uniformity of temperature, and appropriate mixtures of alkali nitrates melting at less than 300°C. are available commercially. It is unnecessary to quench from the precipitation temperature but the rate of cooling should not be so slow that the time of heat treatment becomes, in effect, longer than that intended.

Instrument springs and other products which must be held to close dimensional tolerances can, with advantage, be heat treated in jigs or clamps. Precipitation hardening, especially in the range of over-ageing, tends to eliminate internal stresses from the metal, and articles heat-treated in fixtures will retain the dimensional accuracy of the fixtures themselves.

Fixtures can be made from cold, rolled steel, which is cheaper and easier to machine than die steel. They should be carefully cleaned after use and preserved with a film of oil, which must be removed before they are again put into service. Because of the greater mass of metal, the total period of heating is longer with fixtures than without them, and experienced operators tend to adopt slightly higher temperatures, a practice which encourages stress relief.

Descaling and finishing

Oxide scale formed during the heat treatment of beryllium copper can be removed by pickling in a solution of 1 volume of concentrated sulphuric acid in about 4 volumes of water—preferably used hot. The surface may subsequently be brightened either in cold 30% nitric acid or by a quick dip in a bath consisting of 2 pints of concentrated sulphuric acid, 5 lb. of sodium dichromate and 5 gallons of water. Before being dried, the articles must, of course, be washed thoroughly to remove all trace of acid. Over-pickling may lead to a roughened surface detrimental to the mechanical properties—especially under conditions involving fatigue.

Beryllium copper products can be finished by any of the normal techniques, but for obvious reasons it is desirable to carry out preliminary polishing and to remove surface imperfections before the final hardening treatment. The alloy can be electroplated with all the usual metals but it is important to remove any surface film of beryllium oxide which, although often invisible, tends to impair adherence of the deposit.

A dip in cold 30% nitric acid, with or without the addition of a little sulphuric acid, can be used for the purpose; an alternative recommendation consists of two short dips, first in a mixture of 3 volumes of strong nitric acid and 1 volume of strong sulphuric acid, these proportions being reversed for the second dip; and a dip for from 5 to 10 seconds in 25% hydrochloric acid serves the same purpose.

Chromate films, resulting from the bright dip mentioned above, tend to be detrimental to the adherence of the deposit; like the films of beryllium oxide they can be removed by either of the acid treatments.

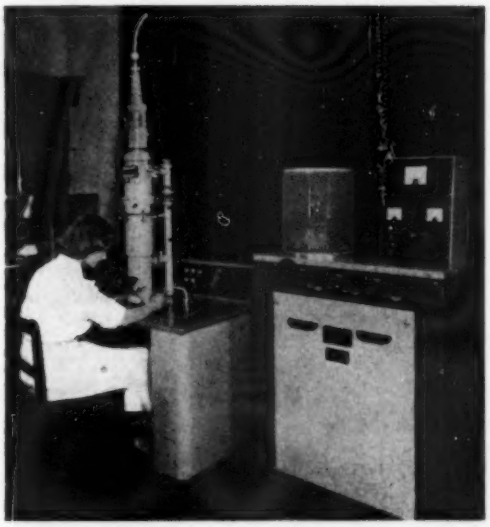
Thorough rinsing is necessary before transferring to the appropriate plating vat. A flash coating of copper is a useful preliminary to plating with other metals and, as an exception to the previous statement, good adhesion can be achieved by flashing with copper from an acid sulphate bath after using the dichromate pickling solution.

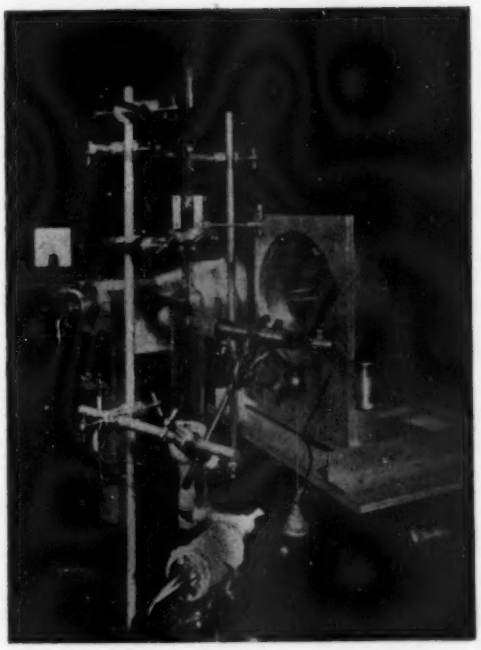
Heat tinting is hardly practicable with beryllium copper, not only because of the protective film of beryllia which forms so readily, but also because the temperature required might well upset the final heat treatment. Chemical colouring can be applied if desired, such as: aqueous potassium sulphide at 40°C. for black; arsenious oxide in hydrochloric acid at 80°C. for steel grey, and liver of sulphur in aqueous caustic soda for reddish-brown to blue-black. The most satisfactory concentrations of these chemicals can best be found by trial; alternatively, various proprietary preparations are obtainable for the purpose. Articles must be quite clean before any attempt is made to colour them, and must be well washed afterwards; lacquering is advisable to preserve the colour.

As sulphur compounds tend to stain beryllium copper, oils, or other substances containing this element should be carefully removed. Either vapour degreasing or alkaline cleaning solutions may be used for the purpose, with or without electrolysis. Tarnish resulting from moist or sulphurous atmospheres can be removed by a short immersion in either a 10% solution of sodium cyanide or in 5 to 10% sulphuric acid at room temperature. Parts should be free from grease and should be well washed afterwards.

Acknowledgments

The author is indebted to the Copper Development Association for the information in this article.





TOP *Electron microscope and evaporation unit*

BOTTOM *High-temperature X-ray diffraction camera in which the structure of reactive alloys can be studied at temperatures up to* 1,000°C. *in vacua of* 10^{-7} *mm. Hg*

Fulmer Research Institute

The Institute was founded to carry out sponsored industrial research, the results belonging solely to the sponsor. The work of the Institute is not confined to any one subject but metallurgy, inorganic chemistry and solid state physics have so far been the principal fields.

Although Government organizations, including U.K.A.E.A., provide the greater proportion of sponsorship, the demand for the Institute's services by industry continues to increase. The larger firms with their own laboratories use the Institute for work outside their normal activities or for the specialized techniques available. The Institute is an approved A.I.D. and D.I.A. test house, and smaller firms, without laboratories of their own, use the Institute for analysis, test work, and consulting services. This is particularly true of local firms. Much of the Institute's income comes from overseas, particularly from the American continent. Some of this is from U.S. Services and some from American and Canadian industry.

Two new single-storey buildings have recently been completed—a physics laboratory and a workshop. The unit cost of this latest extension is £3 4s. 0d. per sq. ft. This includes all services, heating and recirculation, site works and special water-proofing requirements, and all built in laboratory benches and fitments.

The following article gives brief descriptions of some of the metallurgical work completed or in progress and indicates the facilities available for metallurgical investigations

Fields of investigation

Thermochemistry Specialized techniques in the field of physical chemistry include accurate measurements of vapour and reaction pressure using the capillary vessel method developed in the Institute, in addition to all standard methods. These have been used to study the stability of

radicals at high temperatures and to establish activity data for various metallic systems. Accurate calorimetry has established the heats of formation of various compounds, in particular metal halides and intermetallic compounds, and new values for the heats of formation of a large number of important compounds in these categories have been established and published. The kinetics and equilibria of various reactions of interest in the fields of nuclear power and extraction metallurgy have been studied in apparatus requiring highly efficient vacuum techniques.

In physical metallurgy, as well as in extraction metallurgy, free energies and heats of alloy formation are important parameters of intermetallic systems. The following systems have been investigated: iron-aluminium-silicon arc furnace alloys, iron-chromium-carbon, aluminium-manganese, iron-titanium, iron-aluminium, uranium-bismuth, thorium-bismuth, and uranium-silicon. In this work, each system requires a special approach and in the case of the highly reactive uranium and thorium alloys novel techniques are used for preparation and handling.

Extraction metallurgy One of the first investigations carried out arose from the development by Dr. Gross of the well-known aluminium catalytic distillation process. This process depends upon the reversible reaction between aluminium trichloride and an aluminium-bearing material to form a volatile monochloride, which subsequently decomposes into aluminium and aluminium trichloride. The reaction is applicable to the extraction of aluminium from alloys produced by direct thermal reduction of bauxite, or other suitable aluminium-bearing minerals, in an arc furnace, or to purification of scrap. Aluminium of high purity has been produced by this method.

A similar approach has been used in the development of a titanium extraction process in which titanium tetrachloride is passed over ferro-titanium or titanium scrap to form titanium di- and trichlorides which are subsequently decomposed to form relatively pure titanium and further tetrachloride for recirculation. The process has been developed on a laboratory scale and can be extended to the pilot plant stage. A related method has been applied to the purification of beryllium, with promising results.

Uranium Recent work in uranium metallurgy has included extensive phase diagram and transformation studies on binary and ternary alloys. X-ray crystallography is being used to elucidate the structure of uranium chelate complexes, and various uranium and uranium alloy phases. Creep tests on uranium and its alloys have been carried out in compression.

Zirconium and zirconium alloys A study is being made of the ω-phase in zirconium alloys and the Zr-Nb, Zr-Mo, Zr-U and Zr-Cr systems have been examined so far. The ω-phase acts as an embrittling agent during heat treatment of zirconium alloys for use in nuclear reactors. The high temperature X-ray diffraction camera and an apparatus in which specimens can be quenched in helium at 8,000°C./second are used in this work. The mechanism of oxidation of zirconium and zirconium alloys in CO_2 is being studied.

Age hardening The original metallurgical work on age hardening of aluminium alloys supervised by Dr. Hardy, is continuing and this, together with the X-ray techniques developed at the Institute for studying precipitation processes, are well known internationally. Trace elements have been shown to exercise a profound effect on the ageing behaviour in some systems, and the influence of small quantities of cadmium in accelerating the ageing of aluminium-copper alloys led to the development of the aluminium-copper-cadmium alloys, which, while free from room temperature ageing after solution treatment can be aged at slightly elevated temperatures to give properties approaching those of the duralumin type alloys. These alloys have excellent pressing properties and machining stability. Work is in progress to assess the suitability of Al-Cu-Cd for structural work. Trace element effects have also been found in magnesium, copper, and silver base alloys.

Aluminium alloys In addition to the work on age hardening aluminium alloys, various other researches are in progress, including a study of the mechanisms of layer corrosion and stress corrosion in structural aluminium alloys. The influence of thickness of anodized coatings on the corrosion resistance of various aluminium alloys is also being studied and an investigation is in progress on the influence of metallic coatings anodic to the basis metal on the corrosion fatigue of high strength alloys. An aluminium-tin bearing alloy containing up to 30% tin, developed in conjunction with the Tin Research Institute, is being used successfully in industry.

Chromium and chromium-base alloys Research is in progress on chromium metal and chromium-base alloys. Although the aim of the research is the development of alloys for very high temperature service, much more work on the pure metal itself remains to be done in order to understand and overcome its brittleness. This is achieved in various degrees by purifying—especially from nitrogen and carbon—and also by previous warm working treatments and heat treatments. Progress is being made with the extrusion of the pure metal and its alloys using techniques similar to those which have been developed for molybdenum.

Ferrous metallurgy Research is in progress on

low alloy and coated steels for high temperature service. During this work low alloy silicon-aluminium steels with oxidation rates similar to that of 18/8 steel in the 600-950° range have been developed. In recent work the effect of higher aluminium contents is being studied. Other work in the ferrous field has included a study of the effect of composition and structure of cast iron on its resistance to corrosion by sulphuric acid. A study has recently been made of the influence of production variables on the quality of cast iron shot.

Liquid metals Following X-ray diffraction work on relatively 'simple' liquid metals like sodium and potassium, the breakdown in structure with temperature of 'molecular' liquids such as gallium, bismuth and tin is being studied. In addition, interesting results are being obtained on alloys such as gold-tin, in which a high degree of order is detectable.

Equipment and specialized techniques

X-ray crystallography Extensive facilities are available for X-ray diffraction work, and six X-ray generators are in use. Conventional crystallographic methods are supplemented by specialized techniques for studying reactive metals. A high temperature X-ray camera enables readily oxidized materials such as zirconium and titanium alloys to be studied at temperatures up to 1,000°C. in a vacuum of 10^{-7} mm. of mercury.

The structure of liquid metals at elevated temperatures is being studied with a specially designed Geiger counter X-ray diffractometer. Single crystal methods using monochromatic radiation are employed for studying the mechanism of age-hardening and phase transformations. X-ray studies are also being made of the structures of organic complexes and glass.

Electron microscopy A Metropolitan-Vickers EM3A electron microscope is used for reflection and transmission (thin film) microscopy and electron diffraction work. In recent researches, the microscope has been used to investigate the build-up of deposits in oil burning furnaces, the fundamental nature of slip lines, and surface oxidation studies. Other uses include examination of paint pigments and contaminated catalysts, and, more recently, the examination of the structure of fungi cell walls.

Metallography In addition to a Bausch & Lomb Metallograph and a Reichert Metallurgical Microscope, there are several bench microscopes, one of which is equipped for phase contrast microscopy and micro-hardness testing. Conventional heat treatment equipment is supplemented by a vacuum quenching apparatus and a high temperature vacuum furnace which can operate at temperatures up to 2,000°C. with a vacuum better than 10^{-5} mm. of mercury. A special dilatometer incorporating a differential transformer has been constructed for studying isothermal transformations and martensitic transformations on rapid quenching. The apparatus was designed for studying uranium alloys but can be used for studying transformations in most metals.

Mechanical testing (including high-temperature creep and fatigue) The laboratory is equipped to carry out all normal mechanical tests. In addition to impact and hardness machines, a Dennison 50-ton universal testing machine with ancillary equipment for high and low temperature testing is in use. Wöhler, Haigh, 'slipping clutch' and Rolls-Royce machines are available for fatigue testing, and equipment has been specially designed for high temperature fatigue testing of sheet. Interesting information about the initiation of fatigue cracks is being obtained by special replica techniques.

Conventional creep testing apparatus is supplemented by facilities for carrying out creep in compression and in special protective atmospheres. This has proved essential in studies of compression creep of uranium and other highly reactive metals. Both static and dynamic strain gauge measurements have been made on structures under load. This work has been done in the field as well as in the laboratory.

Corrosion Laboratory corrosion test apparatus includes salt spray, humidity and SO_2 cabinets and high accuracy quartz spring balances for studying oxidation in special atmospheres by weight changes.

For atmospheric corrosion the Institute has exposure sites in industrial, marine and rural environments. A novel technique has been developed for non-destructive assessment of corrosion damage in terms of loss of mechanical strength enabling a corrosion/time curve to be found on a single specimen. Electronic equipment such as valve voltmeters, a potentiostat and a constant current device are used in studying cathodic protection.

Electrodeposition Four separate rectifiers deliver direct current supplies up to 250 amps at 60 volts, enabling experimental electrodeposition to be carried out on a scale ranging from beakers to full pilot plant. These facilities are used extensively for the preparation of very pure chromium. A production rate of 25 g. per hour is possible. Work has also been carried out on the electrodeposition of manganese, and on the anodizing and dyeing of aluminium and its alloys.

Melting and casting Apart from the normal oil and gas fired furnaces for melting, induction furnaces have been adapted for melting and casting in special atmospheres or *in vacuo* and for zone

refining as well as for open melting. Most reactive alloys for experimental work are prepared in argon arc melting furnaces, with water cooled copper hearths. One of these is equipped with a retractable hearth, from which small billets suitable for extrusion can be made. An apparatus has been constructed for melting by electron bombardment, and is used for zone refining and growing single crystals.

Metal working A forging hammer and a small rolling mill are available. From the latter either sheet or rod can be produced, and techniques for sheath rolling reactive alloys are well established. There is also a 60-ton press for use with powder metallurgical techniques, and a miniature extrusion press. Arrangements have been made outside the laboratories for the extrusion of highly reactive and refractory materials, some of which have been sheathed and extruded using glass lubrication. This technique has proved particularly valuable in the investigation of chromium and chromium base alloys.

Refractories Special techniques for the preparation of refractories for dealing with highly reactive metals have been developed. A kiln is available for firing refractories at temperatures up to 2,000°C. Ball and roller mills allow the preparation of finely divided material for slip casting or spraying. A diamond cut-off wheel provides for accurate shaping and cutting of thin slices of hard brittle substances.

High-temperature tensile testing

Until quite recently the only figures available in relation to tensile strength were those recorded from the orthodox tensile machine, using test bars pulled at room temperature.

Thompson L'Hospied & Co. Ltd., essentially concerned with heat-resisting steels and their performance at elevated temperatures, do not consider that figures taken at room temperature are of much practical use for those whose job it is to design castings for use at higher temperatures. They have, therefore, incorporated in the tensile machine in their physical testing laboratory an electric furnace fitted with exceedingly accurate control and temperature recorders, by means of which it is possible to obtain tensile figures for any specific heat-resisting alloy at the temperature at which it will ultimately be used.

NEW RING MILL AT WALTER SOMERS

AN IMPORTANT ADDITION is announced to the equipment to the new Light Forge opened last summer by the Hales Owen company of Walter Somers Ltd.—one of the latest pattern Wagner ring-rolling mills.

The new ring mill is capable of rolling rings from 17 in. minimum inside diameter up to 79 in. maximum outside diameter, with a wall thickness from 2 in. to 10 in., maximum face height 12 in. Special tools were designed by Walter Somers' own staff in collaboration with the French firm of M. Dembiermont et Cie, of Hautmont.

The photographs show a ring being rolled on the mill, starting with a blank of 34 in. o.d., 20 in. i.d., 9½ in. high, finishing at 69 in. o.d., 63 in. i.d. and 9½ in. high. The process is handled by one man only, operating two small hand levers at the control desk, and completed in approximately 40 sec., instead of a team of four or five men taking up to 30 min. by forging.

Electrical Aids in Industry *Data Sheet* **No. 7**

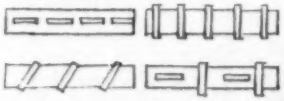
Lighting - 2

The general principles of factory lighting have been dealt with in the previous data sheet (No. 6). This one considers briefly certain factors—not always fully appreciated — that influence the lighting for some particular factory applications. The next data sheet will carry the subject further.

Work benches

The most universal application of lighting is to bench work, for there is no branch of manufacturing that does not have its work benches which, of necessity, are used for a great variety of occupations. No single lighting method is suitable for all cases.

The introduction of fluorescent lighting has gone a long way to solving one of the main problems here; for while the high degree of brightness of filament lamps tends to preclude their use for individual lighting owing to the glare, the fluorescent tube with its greater expanse of light source has made localised lighting with a low mounting height more practicable. Moreover, the length of the fluorescent tube makes it possible to control shadows.



With narrow individual benches (not more than 4 ft. wide), there are four basic methods of localised lighting: longitudinal, transverse, diagonal or a combination of longitudinal and transverse. With wider benches it is not advisable to use fittings directly over benches, and fittings should be behind the workers at each edge of the bench. Where particularly high illumination is required, fluorescent fittings may be mounted as local lights — low enough for the skirt of the reflector to conceal the lamps from the eye of the operator.

High-bay shops

Probably the most difficult of all factory lighting problems is that of high-bay lighting. In lofty, long and sometimes necessarily dirty shops such as those which house really large machine tools and overhead cranes, it requires great ingenuity, coupled frequently with high lamp wattage, to provide adequate illumination. From the planer operator to the slinger, the workman is dependent on good lighting if he is to avoid an over-cut or a serious crane mishap.

The major problems associated with the lighting of high and relatively narrow shops, such as heavy machine shops, are:

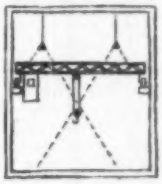
(a) Poor light utilisation caused by excessive light absorption by the large and often dark wall area.

(b) Preponderance of light flux downwards and poor cross lighting causing poor illumination on vertical surfaces, and heavy shadows.

(c) Possibility of heavy light absorption in the atmosphere.

(d) Difficulty of access to high fittings for maintenance.

In high-bay workshops there is a tendency to use concentrating fittings so that the maximum proportion of the light output reaches the working area without spread to the walls, but the saving in wall absorption is obtained only by accepting a depressing environment, poor cross lighting and heavy shadows.



In many cases it is good practice to accept the inevitable reduction in light utilisation by wall absorption and to reduce this by applying light colours to interior surfaces where possible throughout. This approach results in more cheerful conditions and provides equally good illumination values and better cross lighting. Even better is to add angled lighting from the sides below crane level.

In this type of shop, rapid deterioration in light source intensity due to dust must be expected. Facilities should always be provided for easy access to fittings for cleaning and maintenance.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone: TEMple Bar 9434.

Excellent reference books on electricity and productivity (8/6 each, or 9/- post free) are available — "Lighting in Industry" is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity, including one on industrial lighting. Ask for a catalogue.

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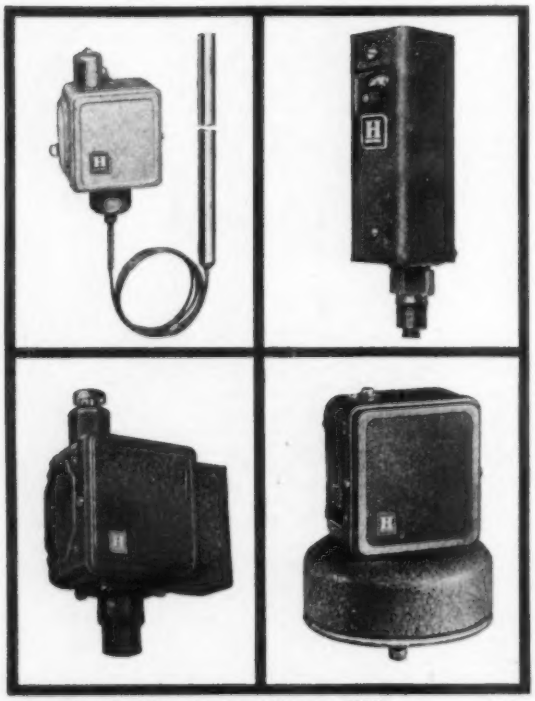

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(Left) Remote Bulb Temperature Controllers—on-off or modulating.
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(Left) Pressuretrols—two-position and proportioning models for liquid and gas pressure from 0—300 psi.
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NEWS

Radioactive branding of steel casts

THE USE OF ISOTOPES for the identification of steel casts was introduced on an industrial scale recently, when Sandviken Jernverks A.B., Sweden, began production of tubes for two heat exchangers for Sweden's first commercial atomic reactor, which is to be erected at Farsta, south of Stockholm.

To each melt of 4·5 tons about 5 g. of a radioactive tantalum isotope was added in the ladle during casting. The isotope, which is kept in an aluminium container, is transferred into the cast by 3-ft. tongs.

The processing of the eight melts of the isotope-branded steel cast so far has gone according to plan. Radiation from the ingots is of sufficient strength to permit identification of the tubes after nine months. On the other hand, the intensity of radiation from the ingots is so low that no special precautions have to be observed in the handling of the material during the rolling and other operations. The radioactive isotope, tantalum 182, which is used has a half-life of 111 days.

This method of branding, which saves a considerable amount of time and money, is also of practical interest in the production of high-pressure tubes for superheaters and steam-power plants.

Forging equipment at Paris Exhibition

Langenstein & Schemman, represented in London by Paul Granby & Co. Ltd., was showing some of its forging equipment at the Paris Machine-Tool Exhibition last month.

A combined hammer and deep-drawing hydraulic press of 135 tons capacity with cast-steel frame and tie-rod construction was shown. This machine is capable of very deep drawing operations, due to the infinitely variable hydraulic pump, which automatically adjusts the speed of the press during the drawing cycle to suit the conditions demanded. The press is equipped with a hydraulic cushion, which can be used as a blank holder and also for ejection purposes. In addition to the deep-drawing facilities, the ram can be made to drop under gravity with either short or long blows, in order to coin or strike the work to produce sharp corners and absolute flatness, also embossing operations.

The other machine on view was a new short-stroke drop hammer, model KH125, which has a 25-cwt. tup and a stroke of 40 in. By combining a heavy tup with a short stroke this machine provides a very high operating speed and, unlike any other drop hammer, it has an hydraulic lift to the tup. On this drop hammer was shown a new LASCO two-height automatic hammer control with instant stroke adjustment. This new development permits two different drop heights to be pre-set and to be automatically operated by electric foot buttons. Each setting is infinitely variable, so that the stroking is steplessly adjustable over the whole length and the machine can be operated with single blows or with a continuous striking. The new LASCO system permits exceptionally accurate blow control from all heights. Die wear is considerably reduced by avoiding unnecessarily hard blows.

Annealing furnace for 100-ton steel forgings

One of the largest electric heat-treatment furnaces in this country is to be built by Birlec Ltd. for the English Steel Co. Ltd., Sheffield, at a cost exceeding £65,000. The furnace is of the pit type with effective internal dimensions 35 ft. deep by 8 ft. dia. and a rating of 1,220 kW. To be used for the heat treatment of alloy-steel forgings up to 100 tons in weight, the furnace will have many special features, including a special control system to ensure very close temperature tolerances and provision for controlling the composition of the furnace atmosphere.

This is the latest of several large Birlec furnaces used by this company for the treatment of heavy forgings, including one 60 ft. deep by 12 ft. dia.

Electrolytic tinning line for R.T.B.

The Head Wrightson Machine Co. Ltd., a subsidiary of Head Wrightson & Co. Ltd., has been awarded contracts for plant valued at over £2 million for the installation of an electrolytic tinning line at the Ebbw Vale works of Richard Thomas & Baldwins Ltd. capable of tinning and recoiling 1,500 ft. of steel strip per min. This line, which will be built at Head Wrightson's works on Tees-side, will operate at a greater speed and a larger output than any existing tinning line.

Additionally, equipment is being supplied for the preparation of steel strip before it is processed in the tinning line, for tin-plate cut-up lines and for equipment to inspect and assort the plate.

Delivery will be made in 18 months and it is being designed in collaboration with the Aetna Standard Division of the Blaw Knox Co. of America, with whom the Head Wrightson Machine Co. Ltd. has been associated for several years.

CENTRIFUGALLY-CAST CARBURIZING POT

The body of the large carburizing pot in this photograph has been centrifugally cast by Thompson L'Hospied & Co. Ltd. with the advantage of homogeneity and greater ultimate strength. The base of the pot is statically cast and welded to the pot so that when wear occurs a new base can be welded to the existing body

PEOPLE

THE COUNCIL of the Institution of Production Engineers announces that the Member's Medal for 1957-58 has been presented to **Mr. A. J. Lawrance,** works director, Kimber-Allen Ltd., for his paper, 'The application of spark erosion machining.'

Mr. H. J. Tucker, Southern Area sales manager of the Electric Resistance Furnace Co. Ltd., for the past 10 years, has become service manager. In his new capacity Mr. Tucker will be able to ensure that users of Efco furnaces obtain complete satisfaction from their installations.

Mr. Tucker, who joined the Efco organization in 1935, will continue to operate from the company's Head Office in Queens Road, Weybridge, Surrey. His services are freely available to customers throughout the country.

Mr. S. R. Howes, O.B.E., has retired from the board of the United Steel Companies Ltd. He was appointed a director in June, 1956, and assumed special responsibility for the company's then newly created department of operational research and cybernetics. Mr. Howes remains managing director of Templeborough Rolling Mills Ltd., in which the company has a financial interest.

Mr. W. T. Hale, sales director of Thomas Marshall & Co. (Loxley) Ltd., has been visiting South America to investigate the possible market for British refractories.

On his return, Mr. Hale said there were good short-term prospects for insulating materials, but as local industries developed the market would probably be restricted to specialized products, such as carbon blocks.

Mr. Hale believes that Britain is missing opportunities in South America because credit terms are not sufficiently flexible to compete with those offered by Germany and Japan. He also emphasized the importance of the follow-up when business had been completed to ensure continuing goodwill.

Marshalls are at present supplying refractories to the Argentine, where there are two blast furnaces in operation, three under construction and four more planned. In Brazil, where 12 blast furnaces are in operation with others being built, an enquiry worth £11,000 was received from Petrobras. In Chile Mr. Hale was asked for quotations, although the small steel industry is mainly supplied with refractories from the United States.

Mr. W. T. Hale

Mr. H. J. Podmore

Birlec Ltd. has established a Midland Area sales office with **Mr. H. J. Podmore** as manager. The new office is situated at the company's main premises in Tyburn Road, Birmingham 24. Mr. Podmore joined Birlec in April, 1955, as sales manager, Dryer and Gas Plant Division.

Mr. W. E. A. Redfearn, director, English Steel Corporation Ltd., deputy managing director, English Steel Forge & Engineering Corporation Ltd., and director, English Steel Rolling Mills Corporation Ltd., has been appointed chairman of the National Forgemasters' Association in succession to the late Sir Frederick Pickworth.

Prof. David Williams, D.SC., PH.D., B.ENG., D.I.C., who occupies the University of London Chair of Mining Geology at the Imperial College of Science and Technology, has been elected president of the Institution of Mining and Metallurgy for 1960-61. He was elected to Associate Membership of the Institution in 1932, to full Membership in 1941, and has served on the Council since 1949, holding office as vice-president from 1954 to 1957.

Prof. Williams will take office in May, 1960, in succession to Dr. J. H. Watson, C.B.E., M.C.

Mr. A. Moore has been appointed area technical sales representative for Brayshaw Furnaces Ltd. in the territories comprising Northumberland, Durham, Yorkshire, Leicestershire, Derbyshire, Northants and Lincolnshire.

OBITUARY

We are deeply sorry to learn of the death of **Mr. Frederick John Shotton** last August at the age of 84.

Mr. Shotton was one of the founder members of the NADFS. In 1918 he was appointed chairman of the Technical Committee and in 1920 he was serving as a full member of the Executive Committee. In 1931 Mr. Shotton was appointed vice-chairman of the Executive Committee and served as chairman of the Association from 1933-36. In 1945, when the new Constitution was formed, he was elected one of the five vice-presidents of the Association. Mr. Shotton served continuously on the Council until ill health in recent years prevented his regular attendance, and has, therefore, given more than 42 years of service to the affairs of the trade Association.

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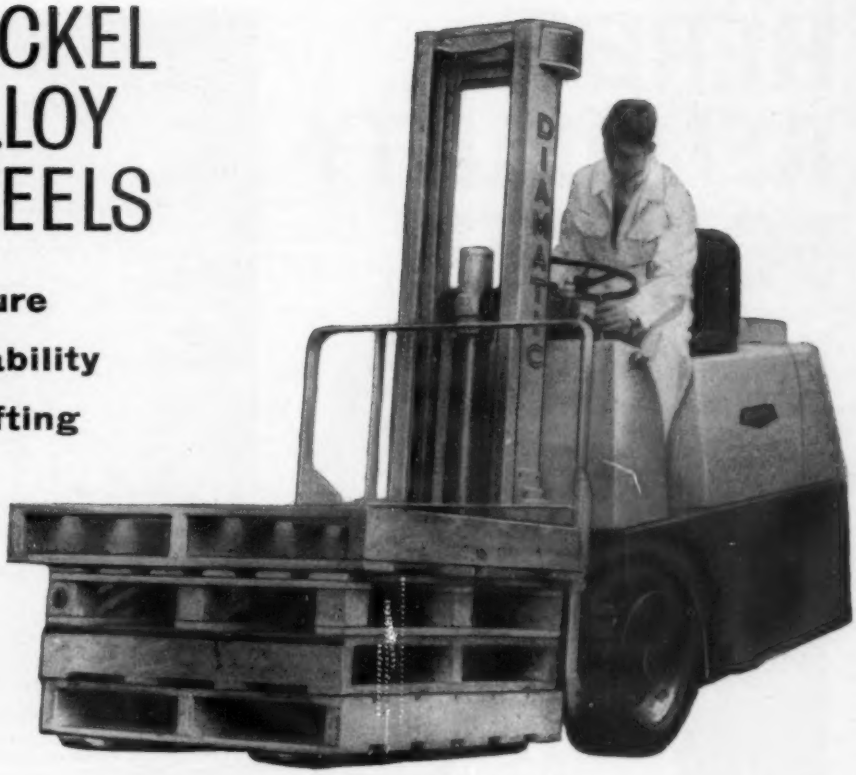

The fork lift truck, of which this Diac model is an advanced design, epitomises the transition of labour from man to machine.

This new unit, designed to achieve high operating speeds and quick servicing, incorporates various components made from eight nickel alloy steels, notably EN 33, the tried and proven 3 per cent nickel case-hardening steel long used for services where fatigue is a factor and wear resistance a requirement.

TYPICAL CORE MECHANICAL PROPERTIES OF

EN33

ARE AS FOLLOWS:

SIZE	HEAT TREATMENT	MAXIMUM STRESS t.s.i.	ELONGATION per cent	IZOD ft. lb.
1¼" dia	Oil quenched 860°C Water quenched 770°C.	56·3	21·5	83
3" dia	Oil quenched 860°C Water quenched 760°C.	47·2	20	92

The benefits to be gained from the more highly alloyed case-hardening nickel steels, such as EN 33, EN 34, EN 36 and EN 39 include ease of heat-treatment, minimisation of processing distortion, and general reliability.

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NEW PLANT

Furnace for small parts

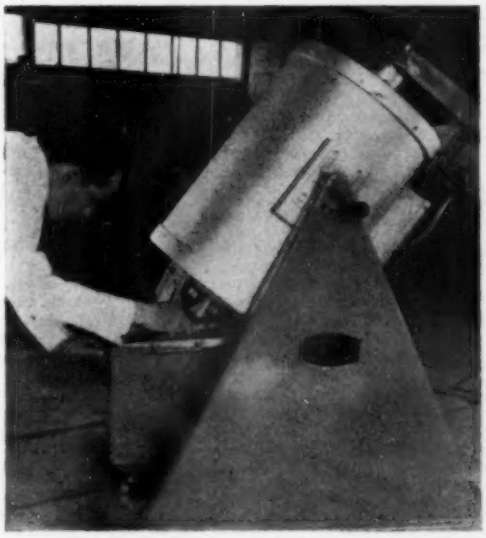
A new type furnace for very small parts has been developed by the Electric Resistance Furnace Co. Ltd. The new furnace is a vertical cylindrical atmosphere furnace combining the advantages of pit-type gas carburizers with facilities for closed quenching hitherto available only in horizontal equipments. The furnace has a vertical cylindrical heating chamber, closed at the top, with provision for inserting a charge through the base. The chamber can be electrically heated with 'Corrtherm' elements or gas fired with radiant tubes. A powerful fan draws the atmosphere up through the charge and forces it down over the heating elements, ensuring uniformity of heating and intimate contact of the atmosphere with all surfaces of the charge.

The tubular furnace has a horizontal heating chamber which can be tilted in two directions, backward to facilitate loading and forward to transfer the parts into an oil quench tank. This furnace has a rating of only 1½ kW. and an overall length of only 3 ft. 6 in. With its facilities for quenching direct from the chamber it is ideally suitable for the hardening of very small pieces, such as watch and instrument parts, which lose their heat rapidly when exposed to ambient temperatures.

The work normally in a nickel-chrome basket is moved into the furnace through an outer vertical rising door to enter a purging vestibule. Here it stands on one of the two platforms of a quench elevator. At the outer door a gas curtain automatically prevents ingress of air when the door is open. Both the door and the quench elevator are pneumatically operated. After purging the charge is transferred to the furnace bung, where it is supported on suitable stools to allow free circulation of the atmosphere. The bung is raised hydraulically to lift and seal the charge into the heating chamber. The heated charge is removed from the chamber by lowering the bung and is then transferred to the quench elevator and lowered into the quench tank.

A feature of the furnace is the use of a charge trolley to move the charge horizontally from the outer loading table into the purging vestibule and to and from the furnace bung. The trolley runs on rail tracks and has wheels mounted on ball bearings. Built into the trolley is a raising and lowering mechanism operated from outside the furnace with a removable push rod. The trolley can be inserted through a swinging counterbalanced flap on the outer door. After use in the furnace the trolley is lowered and withdrawn.

1 *Cylindrical atmosphere furnace for very small parts made by the Electric Resistance Furnace Co. Ltd.*



Metrovick resistance rivet heater

A feature of the Metrovick electric resistance rivet heater is that it is ready for use almost immediately, the first rivet being ready within seconds of the machine being switched on. Thus, where the demand for heated rivets is somewhat irregular, the saving in fuel costs and reduction in waiting time is appreciable. The equipment (Type RH3/17), shown in Fig. 2, has three heads for multiple operator use, each of which is capable of handling rivets from ⅜ in. by 1½ in. to 1¼ in. to 4 in. at an average output of 65 lb./h. Separate transformers are used for each head, so that each may be set on a different tapping if more than one size of rivet is required simultaneously; this also prevents the loading of one head affecting the heating speeds of the others. A further advantage of this arrangement is that a transformer can be removed from one head for maintenance without affecting the operation of the other two heads.

2 *Metrovick resistance rivet heater made by Metropolitan-Vickers Ltd.*

Sintered tool shank material

A sintered tool shank material, Mallory 'No-chat,' possessing remarkable characteristics is now being produced and marketed in Britain by Johnson, Matthey & Co. Ltd., 73-83 Hatton Garden, London, E.C.1. The material is claimed to have an exceptional combination of physical properties: a modulus of elasticity of 40×10^6 lb./sq. in., a density of 16·96 g./c.c. (0·606 lb./cu. in.), a coefficient of linear expansion (100-200°C.) of 5×10^{-6}/°C., together with an ultimate tensile strength of 112,000 lb./sq. in. From these data it will be seen that 'No-chat' has definite advantages over steel as a tool shank material. It has a higher modulus of elasticity and hence greater rigidity and these properties, combined with the high density and inherent vibration damping capacity of the material, mean that tools produce better surface finishes than steel-shanked tools of identical size with a minimum of chatter. The coefficient of thermal expansion of 'No-chat' is half that for steel and is about equal to that for tungsten carbide.

Brinell hardness-testing machine

Edward G. Herbert, which has been building a range of hydraulic Brinell hardness testing machines for many years under licence of the Tinius Olsen Testing Machine Co., Philadelphia, U.S.A., announces a new air-operated Olsen 'Air-O-Brinell,' which was recently introduced in the United States (fig. 3).

This new machine combines the compactness and accuracy of hand-operated models with the operating ease of the motor-driven types; the instrument can be used in the laboratory or on the production line. Eliminating mechanical linkages, deadweights and hydraulics, the principle of the machine is that accurately regulated air pressure is applied by means of a heavy-duty, long-stroke diaphragm to the movable ram carrying a hardened steel ball, which, in turn, applies the preselected Brinell load to the specimen. Upon closing the load valve the ram retracts automatically. Under normal operating conditions only 1·2 cu. ft. of delivered air per minute at a minimum pressure of 65 lb./sq. in. is required to operate the tester. Since the amount of air accumulated in the head of the machine is accurately controlled by an air regulation valve, fluctuations in the air supply above 65 lb./sq. in. have no effect whatsoever on operation or accuracy.

3 *Air-operated Brinell hardness-testing machine*

Load application is positively assured by reason of the air gauge indicating the load which will be applied before the test is made. Simple adjustment of the air regulator valve increases or decreases the air pressure in the machine until the desired load is indicated on the gauge, and once the load is set any number of tests can be made in rapid sequence. The gauge is accurately calibrated for the standard range of Brinell loads of 500, 1,000, 1,500, 2,000 and 3,000 kg.

Fine swarf cleaning

Whereas conventional filtration on alkali spray type metal cleaning and degreasing machines cope satisfactorily with normal swarf, they are mostly unsuitable for the very fine swarf prevalent in modern machining methods for aluminium, cast iron and similar metals.

For these very fine swarfs Dawson Bros. Ltd., of Gomersal, nr. Leeds, have developed a special cylindrical pressure filter which can be fitted to any of the machines in their range of metal cleaning and degreasing plant. The basis of the new filtration system is a bag made of heavy-duty, finely woven nylon fabric, closely fitted over a perforated drum, through which all the recirculated alkali solution is pumped before passing through the jetting system.

Sole agents are: Drummond-Asquith Ltd., King Edward House, New Street, Birmingham 2.

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Apply in writing, stating age, qualifications and experience, to the Personnel Manager, Joseph Lucas Ltd., Great King Street, Birmingham, 19, quoting reference PM/GR/305.

SITUATIONS VACANT—continued

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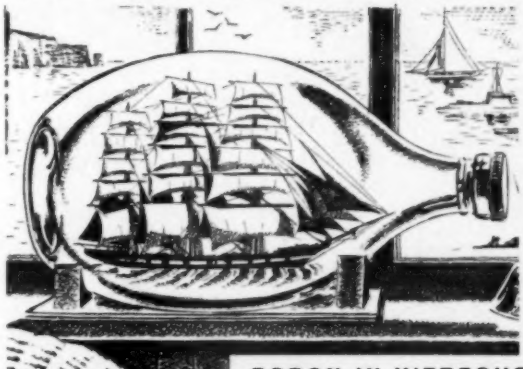

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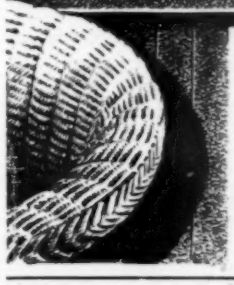

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Photograph by courtesy of Messrs. Marfleet & Weight Ltd. Melbourne, Australia.

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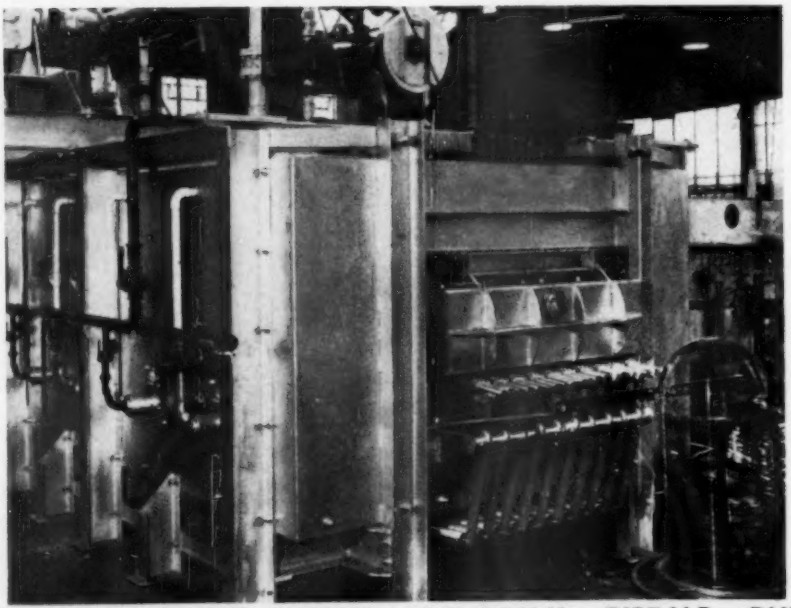

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Work container: 36" diameter × 36" deep. Rating: 60 kW. Electric hoists and quench tanks are available as extras if required.

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Andrews, Thos., & Co. Ltd. .. 36
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Birlec Ltd. .. ..
Birlec-Efco (Melting) Ltd. .. ..
Borax Consolidated Ltd. .. 33
Brayshaw Furnaces & Tools Ltd. ..
Briggs Bros. (Engineers) Ltd. .. 36
British Electrical Development Association 29
British Furnaces Ltd. .. .. ..
Broadbent, Thos., & Sons Ltd. .. 18
Burbidge, H., & Son Ltd. .. ..
Burdon Furnaces Ltd. .. .. ..
Calorizing Corporation of Great Britain Ltd. (The) 37
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Coventry Machine Tool Works Ltd. ..
Cronite Foundry Co. Ltd. (The) ..
Delapena & Son Ltd. .. ..
Dohm Ltd. .. ..
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Dowding & Doll Ltd. 23
Dowson & Mason Ltd. 35
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Electric Furnace Co. Ltd. .. ..
Electric Resistance Furnace Co. Ltd. 15
Electro Heat Treatments Ltd. .. ..
English Electric Co. Ltd. .. ..
English Steel Corporation Ltd. .. 28
E.N.V. Engineering Co. Ltd. .. ..
Etchells, D., & Son Ltd. 10
Ether Ltd. 8
Eumuco (England) Ltd. 19
Fel Electric Ltd. .. ..
Firth, Thos., & John Brown Ltd. .. 35
Firth-Derihon Stampings Ltd. .. 24
Flame Hardeners Ltd. 37
Fuel Furnaces Ltd. .. .. ..
Gandy Ltd. .. ..
Gas Council .. ..
General Electric Co. Ltd. .. ..
General Refractories Ltd. .. ..
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Gibbons (Dudley) Ltd. .. ..
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G.W.B. Furnaces Ltd. 7
Hadfields Ltd. .. ..
Head Wrightson Machine Co. Ltd. .. ..
Hedin Ltd. 36
Herbert, A., Ltd. .. ..
Honeywell Controls Ltd. 30
I.C.I. Ltd. .. ..
Incandescent Heat Co. Ltd. (The) .. 4, 9
Integra, Leeds & Northrup Ltd. .. ..
Jessop-Saville Ltd. 14
Johnson Foster, H., Ltd. 38
Kelvin & Hughes (Industrial) Ltd. .. ..
Kiveton Park Steel and Wire Works Ltd. .. ..
Lafarge Aluminous Cement Co. Ltd. 21
Letchworth Heat Treatment and Hardening Co. Ltd. 37
Manchester Furnaces Ltd. .. .. ..
Massey, B. & S., Ltd. 1
Mellowes & Co. Ltd. 34
Metalectric Furnaces Ltd. .. .. ..
Modern Furnaces & Stoves Ltd. .. 22
Mond Nickel Co. Ltd. 31
Morgan Refractories Ltd. .. .. ..
Morris, B. O., Ltd. 20
Nash & Thompson Ltd. .. .. ..
Newall, A. P., & Co. Ltd. 5
Nitralloy Ltd. .. ..
Nu-Way Heating Plants Ltd. .. ..
Priest Furnaces Ltd. 40
Sawbridge & Co. .. ..
Selas Gas & Engineering Co. Ltd. .. ..
Shell-Mex & B.P. Gases Ltd. 25
Siemens-Schuckert (G.B.) Ltd. .. ..
Sifam Electrical Instrument Co. Ltd. ..
Smethwick Drop Forgings Ltd. .. 11
Somers, Walter, Ltd. 2
Special Steel Co. Ltd. .. ..
Stein, John G., & Co. Ltd. 13
Thermic Equipment & Engineering Co. Ltd. 39
Thompson, Joseph, (Sheffield) Ltd. .. ..
Thompson L'Hospied & Co. Ltd. .. 17
Vacuum Industrial Applications Ltd. ..
Vaughan, Edgar, & Co. Ltd. 12
Wickman Ltd. .. ..
Wiggin, Henry, & Co. Ltd. 32
Wild-Barfield Electric Furnaces Ltd. 3, 26
Wilkins & Mitchell Ltd. .. .. ..
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Wykeham, W., & Co. Ltd. .. .. ..

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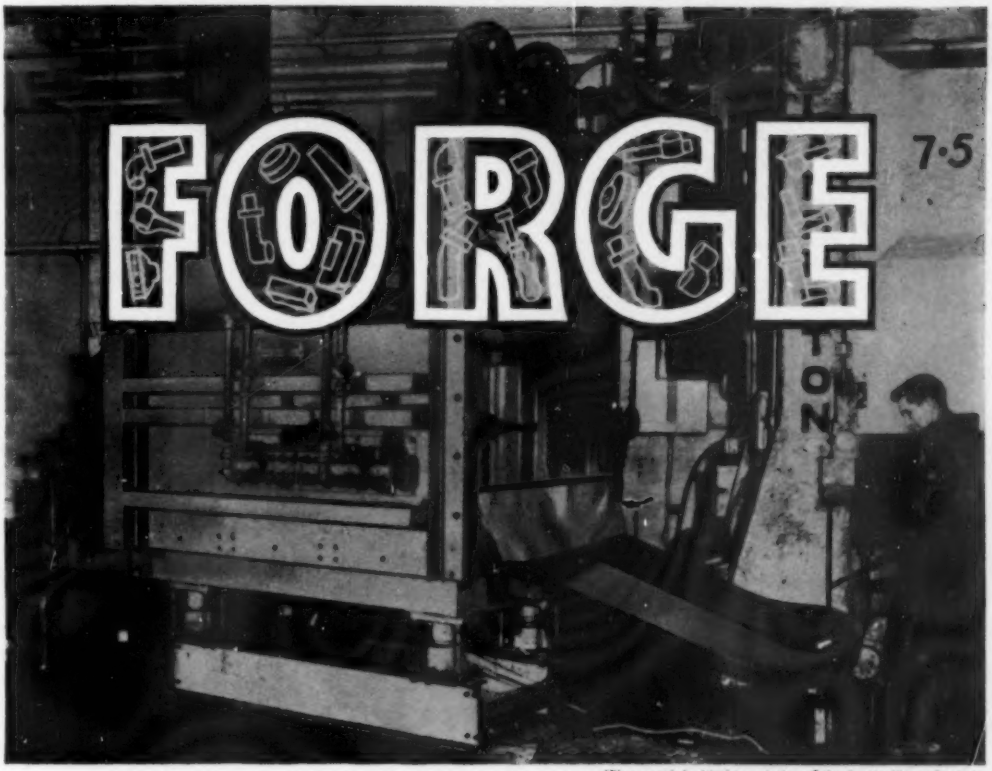

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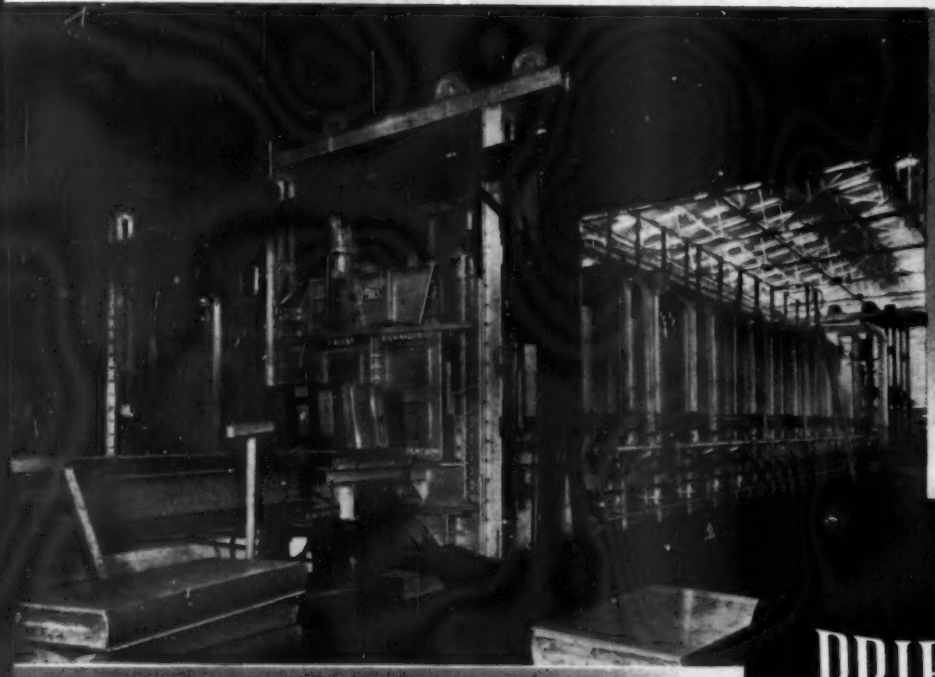

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